A NATIONAL PROGRAM of FOREST RESEARCH.

by

Earle H. Clapp.

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Prepared by

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as the

REPORT *of a* SPECIAL COMMITTEE ON FOREST RESEARCH *of the* WASHINGTON SECTION *of the* SOCIETY OF AMERICAN FORESTERS

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E. H. C.
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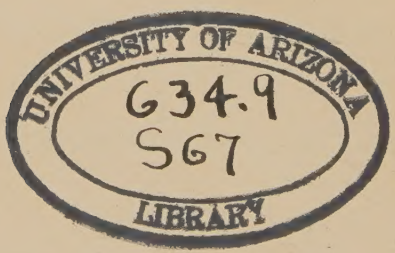

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IS FOREST RESEARCH NECESSARY?

In an address on "The Importance of Forest Research" before the Washington Section of the Society of American Foresters in November, 1924, Col. W. B. Greeley, Chief of the Forest Service, urged action to stimulate and correlate forest research in the United States. In briefest form the reasons for his suggestion were:

1. The outstanding importance and urgency of the forest problem of the United States;
2. The basic place of research in the solution of this problem;
3. The general failure to date to recognize the magnitude and complexity of the research task and to provide for it; and
4. The consequent need for leadership by professional and scientific organizations as a means to concerted national action.

As a result of this suggestion a committee appointed by the Washington Section has prepared the following report, believing that the most effective way to stimulate forest research would be to outline as specifically as possible its place in the national development of forestry; the nature, size, and complexity of the research task; the progress made to date in its solution; and finally, to indicate the agencies which are or should be working upon it. The committee has, in short, undertaken to set up a national program of objectives both in research problems and in the organizations required for their solution. It has also made relatively brief suggestions as to ways and means of correlation.

For the discussion of forest research under way and the agencies engaged upon it, the committee has depended largely upon publications already available. Among these are:

North American Forest Research; Bulletin No. 4 of the National Research Council, August, 1920.

A Classified List of Projects Carried on by the Agricultural Experiment Stations for 1922–23.

Program of Work of the Forest Experiment Stations of the Forest Service, U. S. Department of Agriculture, 1925.

Program of Work of the U. S. Department of Agriculture for Fiscal Year 1919, July 1, 1918.

Program of Work of the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, July 20, 1923.

Grazing Investigative Program, 1925, Forest Service, U. S. Department of Agriculture.

Forest Investigations under way in New England and New York, compiled by the Northeastern Experiment Station, April 1, 1924.

Forest Investigations under way in the Lake States, compiled by the Lake States Forest Experiment Station, March 3, 1924.

Research Laboratories in Industrial Establishments of the United States; Bulletin No. 16 of the National Research Council. December, 1921.

While, therefore, the outline of work under way cannot be complete, it is believed to be enough so to give a fairly comprehensive picture of

what is under way. The record of accomplishments is necessarily based largely upon published results. This check has, however, been supplemented as far as possible from the personal knowledge of the committee. The committee is frank in acknowledging that with the time at its disposal it has been impossible to make an exhaustive check of such results.

For the outline of the research foundation necessary for forestry, the committee has drawn upon existing research programs in the United States; upon the research programs of as many foreign countries as could easily be obtained, which are indicated briefly in the appendix; upon the more recent developments of the underlying sciences; upon such articles as "Forest Protection—Diseases," by Dr. E. P. Meinecke, published in March, 1925, issue of the Journal of Forestry, and that on "The Dendroctonus Problem," by Dr. F. C. Craighead, in the April, 1925, issue of the same publication; and upon its own experience and that of the specialists whom it could easily consult.

Generalized discussion only of all these questions is attempted. A heavy burden of regular duties has not given the opportunity for the exhaustive inquiry which would be most desirable, and accordingly the committee regards its effort as unsatisfactory and incomplete in many respects. Furthermore, such an inquiry is already beginning as a result of the report of the Special Committee of the National Academy of Sciences on Forestry Problems in the United States, to the Academy at its April, 1925, meeting.

THE FOREST PROBLEM OF THE UNITED STATES AND ITS SOLUTION

A broad understanding of the forest problem of the United States and how it must be solved constitutes the only satisfactory background for a critical analysis of the need for forest research, of its urgency, and of the character and size of a national program.

The phase of the forest problem that ordinarily receives attention is that of supplies of timber adequate and suitable for our large and diversified national requirements. That the contribution of forest land and forests to the national welfare may in addition to timber include indirect influences such as watershed protection, forage for livestock grazing, a home for wild life, and areas for recreation, is less well recognized. During the last few years, however, the recognition of these additional phases has been growing. The forest problem must therefore be stated in terms of timber requirements and of forest land use producing this timber, a series of other products, and additional but less tangible economic and social benefits.

1. THE TIMBER SUPPLY PHASE AND ITS SOLUTION

Abundant timber of suitable quality at reasonable prices is vital in the United States to the extent that it is essential for national development and high standards of living. The products of the forest—lumber, fuel wood, ties, mining timbers, naval stores, and paper, as a few examples only—are used directly or indirectly in every human activity.

So much of the use is indirect, however, and so much of the direct use is still taken as a matter of course that Americans generally underrate

the real need for wood. We could, to be sure, exist without wood just as without steel, cement, coal, or without such food products as wheat, but the losses in lower standards of living and in restrictions to industrial development would be almost incalculable. Picture, for example, the American home without lumber, the American farm without wood fuel, any American industry without wooden or fibre boxes for shipping its products, or without lumber for a myriad of uses, our coal mines without mine props, our railroads without wooden ties, the American people without newsprint, and then decide whether we can let wood pass out of our national life.

An enormous volume of timber stored in virgin forests concealed for many years the real nature of the timber supply problem. Even today fully 90 per cent of the cut of high-grade saw timber is being taken from stored supplies in the remaining virgin forest. But our original forest area of 822 million acres has, chiefly during the last fifty years, been reduced to 139 million acres of virgin forest. An original stand, undoubtedly far exceeding 5,200 billion feet board measure, has fallen to about 1,600 billion board feet of virgin timber. On some 250 million acres of cut- and burned-over lands, second-growth forests, occurring largely in scattered, broken, volunteer stands of relatively inferior size and quality, contain an additional 600 billion feet of saw timber.

Although for some products the use is decreasing, there seems to be little likelihood that the future demand for wood will be less than the present. Lumber consumption for 1923 of 37 billion board feet is 9 billion feet short of the peak year of 1907. But our consumption of paper has doubled each decade for the last forty years. There is reason to believe that our total consumption of timber is not falling off and that as a result of high prices the total is already less than actual requirements. An increase of 40 million in our population to the 150 million estimated for 1950 promises the present level of consumption as a minimum if the wood can be obtained. But even this level would entail a drastic reduction in per capita use. Steadily increasing consumption of the most progressive European countries such as England and Germany during the last half century are an indication of our own probable tendencies, as is also the increasing world demand.

The trend in world use and especially in the great industrial countries is itself a good indication that the need for timber can be met only in part through substitution of other materials. Substitution for wood in the United States of such products as steel, cement, and coal, particularly during the last thirty years, has absorbed very largely a demand which would otherwise have called for more wood and has made the rate of increased use relatively low instead of very high. Decreased use for some purposes has, however, been offset by increased use in others. Substitutes more suitable for the purpose intended and at equal or lower prices are economically advantageous; but under opposite conditions, substitution, though it may be feasible, will retard development, reduce standards of living, and should be made unnecessary. Finally, most substitute materials, unlike wood, are unrenewable. Sooner or later, because of shortage of supplies or the advancing cost of exploitation or the price of substitutes, we shall be forced to husband them, and the substitution trends of the last few decades may in part be reversed if wood is available.

Our future timber requirements cannot be met by imports from foreign countries except in relatively small measure and at high prices. Hardwoods can probably be obtained from the tropics in relatively small quantities by outbidding other nations and paying high costs of delivery, but hardwoods now form only one-fifth of the consumption of such an important product as lumber. The tropical hardwoods imported will probably be chiefly in the luxury class and largely beyond the purse of the average man. The world's supplies of softwoods or conifers are much smaller than of hardwoods and world competition will be much more severe. Three-fourths of the world consumption of saw timber, for example, is cut from coniferous forests, and present replacement by growth probably does not exceed 85 per cent of the cut.

Still one additional angle of the timber supply question is necessary to a complete picture. Even under present-day economic pressure of demand and price approximately two-thirds of the entire cut from our forests is lost, either in manufacture or use—in part unavoidably, to be sure. But much of this loss could be saved in manufacture or given longer life in use were knowledge made available and applied. Waste is therefore a large element in the present drain on our forest and better utilization is correspondingly important in our future wood economy.

We must therefore have timber in the future for the maintenance of high American standards of living and continued industrial development. We cannot hope, except in small part, to meet our demands either through substitution of other materials or through imports. The maintenance of even present levels of total consumption will entail drastic reduction of per capita consumption. On the entire area of our forest land, nature, largely unaided except during the last two decades, is now replacing the annual drain by new growth of only one-fourth. This growth must be increased as rapidly as possible to the full growing capacity of our forest land. We can make existing supplies go farther and reduce the amounts which it would otherwise be necessary to grow, or increase the amounts available for actual service, by cutting down losses in manufacture and use. The solution of our problem of timber supply lies primarily, therefore, in timber culture coupled with improved methods of manufacture and use. Both are essential and both are urgent.

2. THE FOREST LAND USE PHASE AND ITS SOLUTION

In addition to the 139 million acres of virgin timber and 250 million of second growth, the 470 million acres of forest land which remain in the United States includes also 81 million acres now unproductive through cutting and fire. The forest land area consists mostly of the marginal, submarginal, and even poorer lands in the agricultural districts, and of the higher, rougher, more mountainous areas.

It is a startling fact that, excluding farm woodlots, approximately 181 million acres of forest land have been cut over or burned over during the last fifty years and thus have been partially cleared and prepared for agriculture but have not been appropriated. This completely disproves the once common belief that all forest land could be used for agriculture. Barring the last decade, this has occurred despite the most ravenous land hunger of our history. The trend of thought in agricultural economics, accentuated by the recent years of agricultural distress, is that more in-

tensive cultivation of the better lands will leave the submarginal land and even much of the marginal land for other use. The latest surveys of the Department of Agriculture indicate, in fact, that an area in excess of the present total of 470 million acres of forest land may become available for timber growing or purposes other than agriculture.

Only within the last few years have we begun to appreciate that the submarginal and marginal lands which cannot be used for agriculture become an intolerable burden if allowed to remain unproductive. Many of the effects of this burden, such as taxation and the reduction of transportation facilities such as railroads, can be measured. The taxes which unproductive forest land districts can pay are much too small to build and maintain schools and roads even for a sparse population, and the surrounding country and in fact the entire State in which they occur must pay the deficit. Unfortunately the evil of nonuse extends also to many phases of social welfare. The population of such districts deteriorates through isolation and the hopeless struggle against adverse economic and social conditions.

The forest land areas which cannot be used for agriculture and which are an economic burden and a social curse if not used at all are a large potential source of wealth in forest products essential to a normal and healthy national life. The present forest land area of 470 million acres can eventually under intensive forest practice be made to grow as much as 27 billion cubic feet of timber annually, and possibly more. The production of this crop will constitute an entirely new timber-growing industry comparable to agriculture, which now crops about 360 million acres in the entire United States. To a large population in regions which would otherwise be largely waste, it will afford a healthful, wholesome outdoor life. It can be made an important adjunct to agriculture on 150 million acres of farm woodlots. It will furnish in perpetuity raw supplies for a wide range of forest industries, which in turn will give employment to a large and stable population. Even assume wood to be a material only sufficiently desirable, if available, to hold its place in our markets at reasonable prices, instead of the virtual necessity which it is. Then the mere possibility of land productivity in place of land idleness would fully justify the growing of timber crops. Despite its wealth the United States cannot afford to impose upon agriculture and other productive industry the unnecessary burden of carrying an area of idle land larger than that now under intensive agricultural cultivation.

The timber product of the farm woodlot, which is not subject to the violent price fluctuations of agricultural crops if past history is a guide, can in many regions be made an important element in diversified farming. Timber can be held almost at will or harvested in time of slack farm labor or financial stress. Furthermore, a profitable crop for marginal and submarginal lands will gradually tend to remove these lands from agriculture and thereby attack at the ultimate source a long list of our agricultural ills, including overproduction and the temptation to unprofitable production which they so frequently offer to the unwary farmer.

The use of forest land should not stop with the growing of timber. We can, as well as not, derive large additional services from it of several kinds. In many forest regions such as parts of the western mountains forage can be grown as a basis for a livestock industry and thus aid in

supplying our meat requirements and supporting adjacent communities. Forest lands are natural recreational areas, occurring as many of them do in the more remote and mountainous districts, and a forest cover constitutes one of their greatest charms. They can be made to better the national health, through outdoor recreation, and to supply food in the form of game. Wild life in general will add to their appeal. The water power which even more in the future than now will be one of our outstanding sources of power depends largely upon forest growth for the regulation of streamflow and the prevention of silting in reservoirs. Water supplies for irrigation have a similar vital dependence upon a permanent forest cover.

In the case of no other needed and renewable products of first importance than wood do we face the same uncertainty as to future supplies. In the case of land we must choose between a high productivity and a veritable desert nearly a half larger than the forest area of all Europe, excluding only that of post-war Russia. The forest problem of the United States is therefore one of our outstanding economic and social problems. It is not too much to say that we must have timber and we must use the land. Fortunately the solution of both phases of the forest problem lies in one and the same measure, the growing of timber on this land. Magnificent virgin forests have shown the possibilities; our task is to repeat what nature has done and to improve upon it. We can also produce livestock and game for food, create opportunities for recreation, and insure the maximum utility of streams for navigation, water power, and irrigation.

3. PROGRESS IN THE SOLUTION OF THE FOREST PROBLEM

Although the American people have awakened very slowly to the importance of the forest problem, they have been acting on it during the last thirty years with characteristic energy. Thirty-four States and the Federal Government have already organized forest services, and the number of States is increasing. The Federal Government now holds about 89 million acres of forest land, and approximately 94 per cent of this, chiefly in the National Forests, is under a form of forest management designed to restock cut-over areas and to insure sustained yields. Similarly 80 per cent of the 8,700,000 acres held by the States, and approximately one-half of the 450,000 acres owned by municipalities, are for the most part under less intensive management. The United States and several States are acquiring more lands. The remainder of the forest land area is in private ownership, about 150 million acres as farm woodlots, and 221 million in larger holdings of lumber, pulp, and other companies. While the percentage of privately-owned land under management is relatively small, possibly from 5 to 10 per cent, there are notable exceptions. Possibly half of the redwood forests of California are being placed under management, and an appreciable percentage of those in the Northeastern States fall in the same category. An increasing number of lumber companies in the South and other important forest regions are moving openly or quietly towards a better handling of their forest lands. The best silvicultural practices are necessarily crude and are based largely upon data so far obtained by research on American species or upon European analogies. Crude though our present practice must be at best, it needs only application to insure continuous if not full timber crops on our land.

A 1922 estimate showed 54 per cent of our present forest acreage to be under fire protection of varying intensities and efficiency, including in part 98½ per cent of Federal lands and 43 per cent of those privately held. Another striking measure of the additional protection required is 92,000 fires in 1924, which burned over more than 22 million acres of forest land with a damage exceeding $38,000,000.

Total forest planting to date aggregates about 1½ million acres and is progressing at the rate of 35,000 to 40,000 acres per year. The annual capacity of State forest nurseries alone was about 55,000,000 plants in 1922. Prior to 1910, 26 States had passed tax laws, usually in the form of optional rebates, bounties, or exemptions, to induce forestry. About 12 States subsequently enacted laws most of which embody the so-called yield tax. The United States has now 22 forest schools and in the neighborhood of 3,000 trained foresters, the number of whom is being increased by nearly 200 men a year. Progress in forest research will be shown later in detail, as will also the progress along such special lines as the control of fungus diseases and insect epidemics.

Encouraging though this remarkable progress is, those who know the situation best realize that it is only a beginning. Still more encouraging are the many indications which point to increasingly rapid progress along all lines in the future.

This in brief categorical form is the forest problem of the United States, how it must be solved, and the progress made in its solution. This is the background against which the need for forest research must be considered and a national research program formulated. For the growing of timber crops on an area of forest land exceeding by 100 million acres that under cultivation in farms, for the full use of the wood product, for the effective production and utilization of other products, the question is whether research is really necessary and good national economy.

IS FOREST RESEARCH NEEDED IN THE SOLUTION?

We live in the age of the highest intellectual attainment, the greatest human welfare, and the most rapid progress that the world has ever known. It is also the age of greatest research activity. There are many reasons to believe that there is a direct relationship between the two. The most progressive nations are without exception those which have engaged most extensively in research. An atmosphere of research pervades our American universities. A fair proportion of our best students are turning to scientific investigation as a career. Wealthy men are founding research institutions with princely incomes solely to increase the sum total of knowledge and thereby to advance human welfare. The most progressive of our industries maintain enormous research institutions to cheapen their manufacturing processes, to raise the grade of their products, and to insure themselves a place in the sun. The number of concerns which take research problems in a consulting capacity grows apace. Municipalities, States, and the Federal Government enter increasingly into the research field in order fully to serve their constituencies. The field of research broadens almost from day to day; already it covers all forms of life, all material things, our universe and others far beyond, and all the forms and materials and laws of nature; and sooner or later we use

all the knowledge so obtained for the material, intellectual, and spiritual betterment of man. Medicine, hygiene, and nutrition, all the materials, processes, and uses centering in electricity, those which are based upon petroleum and the coal tars, most of modern metallurgy, and even agriculture, depend absolutely upon research for future progress, as they have to a large extent for their present status. The question which we now face is whether and to what extent research has a place in the solution of the forest problem.

Two methods, and only two, can be used to obtain the knowledge which no one will deny that we need fully to supply our timber requirements and to utilize our forest land. The first is the gradual building up of such knowledge through long commercial trial and use and the handing down of results by tradition. It is essentially the method of trial and error. The second method is through research.

The first method would obtain knowledge of timber culture and timber use from going large-scale commercial operations. Observations of results by men in the regular industrial forces and untrained for this purpose would too frequently be haphazard and general, too often lacking altogether, and without specific or in most cases even general plan. Despite their excellent purpose, such observations would tend to be unsympathetic, run the risk of missing crucial points, be liable to error, and would rarely if ever give the why and wherefore even though they might ultimately obtain fairly satisfactory results. Long periods of time would necessarily be required for even fragmentary superficial knowledge. Results could never be final and conclusive and never could be based on an understanding of fundamental laws. The total cost, direct and indirect, counting losses from large-scale trial of poor methods and inevitable delays, would be very high.

The research method, on the other hand, would employ highly trained investigators who would devote their full time to finding the facts which underlie the growing and use of forests. They would work plan-wise on the most important, far-reaching, and urgent phases of the problem requiring solution. Most if not all their observations would be on such a scale that results could be closely observed and intensively studied. The ultimate whys and wherefores, the basic laws, would be ascertained. Conclusive findings would be obtained in a much shorter time and at much lower costs. While in general, therefore, there seems to be little or no question of the relative advantages of the research over the trial and error method, the more important lines of forest research should be examined before reaching a final conclusion.

1. IS RESEARCH NECESSARY FOR FOREST MANAGEMENT?

The magnitude of the national timber-growing task must be taken into account in deciding between the two methods discussed in the preceding paragraphs. Present growth on our forest lands is estimated at 6 billion cubic feet of wood annually. It is estimated that this production could be somewhat more than doubled by fire protection and simple methods of timber growing already known. Unfortunately, however, 14 billion feet is but little more than half the present drain on our forests, and future requirements will equal if not exceed those of the present. Much

of the gap between a potential growth of 14 billion feet and our total requirements can only be filled by intensive practice. The filling of this gap, the technical methods for which are still largely to be determined, constitutes one measure of the size of the task, the solution of which lies either in research or in trial and error.

The magnitude of the task may also be measured by the size of the area on which timber must be grown. It exceeds by about 140 million acres the forest area of all Europe except post-war Russia. It is more than one-fourth larger than the area devoted to agricultural crops in the United States in 1919. And it is almost exclusively to the solution of the problems of the latter that the States and the Federal Government are wisely spending approximately a score of million dollars annually and devoting the efforts of fifty or more large research institutions.

The complexity as well as the size of the timber-growing problem should be taken into account. The territory within which the forest land lies has a maximum north-south and east-west extent of about 1,600 and 2,800 miles, respectively. Its forests rise from sea level to an altitude in the eastern mountains of 6,700 feet and in the southern Sierras of 12,500 feet. Climatic extremes range from the subtropical areas of southern Florida and Texas to north temperate conditions in such forests as those of northern Maine, and to subarctic conditions on some of the higher mountain ranges. Climate varies also from that of the northeastern coast, influenced by the Labrador current, and that of the Pacific Northwest dominated by the Japan current, to the continental climate of the interior. Precipitation reaches nearly 140 inches in the Pacific Northwest but falls as low as 20 inches in the interior Rockies, which constitutes about the minimum which will support forest growth. No one knows the number of soil types within this continental area. These wide variations in conditions have in number of species and the varied excellence of their properties given the richest temperate forests of the world. Europe, for example, boasts a total of some 30 arborescent species, of which 7 or 8 are of first commercial importance, while the United States has some 850 arborescent species, of which approximately 65 are of first commercial importance.

All of these species differ in life processes, life histories, in requirements of soil, moisture, climate, and light, in their susceptibility to fire, insects, and disease, and in their reactions to cultural operations. The forester must, however, deal largely with the forest association or type which in some cases is made up of a single species but ordinarily of two or more. With 850 species the number of types is large. New England foresters, for example, have adopted a classification of 21 types for their relatively limited territory alone, while those of the southern Appalachian Mountains have decided upon 28.

A decision between research and large-scale trial and error should take into account what we already know about timber growing and the urgency of national needs for timber. We began two or three decades ago with only the knowledge transferred from different European species and conditions. We had no timber-growing tradition. We did not have the great advantage of the rule-of-thumb empirical methods developed in agriculture through long centuries and upon which agricultural research has improved. Although, considering the handicaps of funds and trained

men, we have since made remarkable progress through research and practical trials, practically the entire basis of knowledge for intensive timber culture in the United States is still ahead.

Furthermore, a multitude of owners of forest land hesitate to begin the large-scale growing of timber until they have some assurance that known and demonstrated cultural methods give reasonable promise of success and profit. We have forestry in public opinion but far too little in the woods. Without traditional methods to remove misgiving and uncertainty, and with research in its infancy, far too many owners for the national welfare will want to hold back to let someone else do the pioneering. This will delay progress not only in developing methods by trial and error, far too slow at best, but it will also retard the whole movement to grow timber and utilize forest land.

Meanwhile the forest problem presses increasingly for solution. Timber utilization continues at four times replacement. Fire, ax, and saw, and insects and disease eat into the last virgin stands with appalling rapidity. Lumber prices increase. The average man goes without the timber essential to the living standards we have come to regard as an American birthright. We increase our imports of paper or its raw materials from 24 to 53 per cent of our paper requirements within the span of twenty-three years. The area of idle forest land grows and with it the inevitable economic and social burden.

From every point of view, therefore, the research method seems to be the logical and practical choice for the solution of the forest management problem.

2. IS RESEARCH NECESSARY FOR FOREST PROTECTION?

The frequent assertion that protection from fire is 75 per cent of the problem of timber growing in the United States, whether literally true or not, conveys a commonly accepted idea of its importance. The number of forest fires reported for the United States has averaged about 47,000 annually from 1916 to 1924 and a vast number undoubtedly have not been reported. The average area burned over each year is conservatively reported at about 10½ million acres, since it is probable that fully 20 million acres have burned over each year in the South alone. Damage, upon a very unsatisfactory basis, was estimated in excess of $40,000,000 in 1918. These forest fires vary from those sometimes thought to be a benefit, or those too commonly regarded as "harmless" because they are thought to consume only dried grass and leaves, to the conflagrations in some coniferous forests which destroy everything in their path.

Only the last decade has seen more than rule-of-thumb conceptions of what is necessary in the prediction of fire conditions and in other forms of fire prevention. The fighting of fires has been, and too much of it probably still is, in the war-club stage. Until nearly the present day, experience has formed the chief basis for expenditures in the United States which now probably aggregate at least $7,000,000 a year. Unfortunately experience may or may not be a fully satisfactory guide and it may or may not be handed down effectively by tradition in rapidly changing administrative organizations.

The question here again is whether it is better to depend upon large-scale trial and error or upon research for the definition of what really

constitutes dangerous fire conditions, and for effective methods of prediction. It is equally a question whether the man who toils on the fire line can work out the complex laws of forest fire combustion with infinite variation in conditions of fuel, weather, and topography, and can tell how to take the greatest advantage of this knowledge in the suppression of fires. It is almost a question of whether in suppressing forest fires of the future we prefer to depend upon the man with a strong back and a shovel, or the man who brings to his task all the aid that science can give. The research method involves the expenditure of a fractional part of the current forest fire costs and losses in obtaining a scientific and authoritative basis for future practice.

Forest tree diseases call for another form of forest protection. Their destructive power is exemplified in the chestnut blight introduced from the Orient in the late '90s, which has all but exterminated the American chestnut throughout its northern and is now sweeping through its southern range. Accordingly but little hope of preserving for future forest culture one of our most rapidly growing and valuable native hardwoods is now offered. The threat of fungus diseases is further shown by the white pine blister rust introduced from Europe in 1898. It is now established and is being fought throughout must of the range of white pine in the Northeast and the Lake States. It has also become established in British Columbia, northwestern Washington, and in western Oregon, and seriously threatens two of the most valuable pines—the western white pine of the northern Rocky Mountains and the sugar pine of California.

Perhaps even more serious in aggregate damage are the heartwood rots which are less spectacular because they do not ordinarily kill the tree. As a result of their ubiquitous attack, wholly sound stands of timber of merchantable size in either the virgin or second-growth forests of the United States are rare. The loss from decay, which is ordinarily as high as 10 per cent of the total yield and frequently reaches 25 per cent or even more, is so common that it is taken almost as a matter of course, regardless of its amount, rather than as the result of largely preventable disease. Forest pathologists estimate the total cull in existing timber stands in the United States at a minimum of 300 billion feet board measure, or about one-seventh of the total estimated stand.

The decision comes down to whether we shall select the woodsman whose job is primarily other things or the most highly trained investigator, to work out the obscure life histories of forest fungi, the forms of management which will keep the forest most free from disease, other means of prevention, the way to control the diseases which do start, or in short the vulnerable spots where alone attack can be undertaken or possibly succeed? Here again relatively inexpensive research seems to be almost the sole possibility of preventing losses which run into billions of cubic feet of timber and hundreds of millions of dollars each year.

The Bureau of Entomology places annual losses caused by forest insects to standing timber and forest products in the United States at $150,000,000. Some fifty years ago the larch sawfly nearly exterminated the eastern larch as a commercial tree in the northeastern United States and Canada. With a rapidly growing demand for pulpwood in the United States and Canada a new spruce budworm epidemic has during the past few years followed several previously known, and has taken a toll in

Maine alone of approximately 27 million cords of spruce and fir or some 40 per cent of the stand. In Quebec the loss is estimated at 200 million cords. One epidemic in Canada and the United States has therefore destroyed the equivalent of more than 25 years' pulpwood supply for current annual American paper requirements, which are now more than half of the requirements of the entire world. Protection from the attacks of insects, of which the preceding are merely examples, is therefore as essential in timber growing as protection from fire and fungus diseases.

As with fungus diseases, the choice lies between men untrained for research regardless of what their other qualifications may be, working by the method of trial and error, and the highly trained investigator, to obtain that knowledge of insect life, environment, relationships, and attack, of the prevention and control of infestations, and of the necessary adaptations in forest management, which are absolutely essential if the people of the United States are to have the timber they need. The relative possibilities seem to leave little room for choice.

Forests require additional protection also from game and other animals and from wind and storm, but these need hardly be treated here because for effectiveness they obviously have the same need for research as fire, fungi, and forest insects.

3. IS RESEARCH NECESSARY TO DETERMINE FOREST INFLUENCES?

One of the most important products of the forest is the influence which it exerts, among other things, upon streamflow and erosion. Flood damage and that from erosion in the United States run into scores of millions of dollars every year. No one knows exactly how much, but the total is staggering. Causes and effect are often far removed and hence unappreciated. If there are practical ways of reducing the loss we cannot afford to let it continue. Most streams of importance rise in the forest. If at the headwaters they take on a load of detritus and reach flood stages because of excessively rapid run-off, they cut their banks throughout their entire course, overflow lowlands, wash away or bury agricultural land, fill costly reservoirs, block channels and stop or interfere with navigation, reduce the water available for irrigation, reduce power output, and damage or destroy many other forms of property.

Within broad limits the influence of the forest is obvious, but definition is difficult. If we knew, for example, the extent to which the forest could reduce flood and erosion losses and in what form it should be to render the maximum service, we should be in a much better position to decide whether it should be used and how and where. The question is whether such information can be obtained most effectively through research or by other means. Furthermore, streamflow and erosion are merely examples of the influences of the forest which are important in human economy.

4. IS RESEARCH NECESSARY FOR FOREST RANGE MANAGEMENT?

Forestry, like farming, involves the use of many kinds of land, which are usually intermingled even in single holdings. Each kind of forest land is best adapted to a certain kind of forest crop, but in addition it

can sometimes produce secondary crops. In order to make forestry most profitable, or financially feasible at all in some cases, it is necessary not only to produce these secondary crops but to produce them in such a way that they benefit the primary crop, or at least do not interfere with it. As in farming, the highest use of land may require diversified use.

The secondary crops of forest land may be of many kinds, but among the most important are forage, wild life, and recreation.

Research, as contrasted with trial and error, is peculiarly important to the successful production of secondary forest crops for four reasons: (1) Heretofore they have usually been "wild" crops, hence little is known about them. (2) Secondary crops, in their effect on the primary crop and on each other, may be anything from beneficial to prohibitive, even in a single locality. Hence, knowledge for their skillful management may be vital to the success of the whole forestry enterprise. (3) Public interest in a secondary crop may be greater than in the enterprise as a whole. Hence, knowledge for skillful adjustment may be necessary from the standpoint of good will and public support. (4) Last and most important of all, the interrelation of forest crops invariably constitutes a single problem in environmental relationships, or ecology, very difficult of solution except through research.

Some random examples of the bearing of these four assertions will help elucidate the importance of secondary crop problems, the great extent to which they remain unsolved, and the fact that they are fundamentally ecological in nature.

In the National Forests of the West, for instance, grazing permits have so far produced approximately as much income as the sale of timber. By careful range management, this income from grazing is in general being produced without detriment to timber production, and in many instances the reduction of inflammable hazards by grazing is positively beneficial in the protection of the timber.

In most woodlots of the corn belt, on the other hand, there is little doubt that grazing is preventing timber reproduction almost altogether, and also greatly slowing down the growth of the forest. The indications are that the actual grazing value of these woodlots is low, and that their productivity as forests is being sacrificed for a smaller value as pastures.

In the National Forests and the corn belt woodlots we have, therefore, important examples of the use and misuse of pasture as a secondary forest crop. Why is grazing used beneficially in the one case and harmfully in the other? Partly, at least, because the methods of range management on the National Forests have been based on at least tentative research findings, while woodlot pasturage is merely a pioneering custom of trial and error that has persisted regardless of its merits from the viewpoint of scientific land use.

The western yellow pine forests of the Southwest present a more localized instance of the fact that the use of a secondary crop like forage may be anything from beneficial to prohibitive, from a timber production standpoint, even in a single locality. Research has shown that over a period beginning a few years previous to the harvesting of the mature timber, and lasting until the reproduction has passed the seedling stage, sheep grazing is likely to be prohibitive of pine reproduction and exclusion may be necessary if a new crop of pine is to be established. Research

has likewise shown that exclusive of this period, moderate sheep grazing in yellow pine may be beneficial by preventing too rank a stand of grass and thus reducing fire hazard. Under some conditions cattle grazing has also been found to be injurious. In this region, then, grazing may be noninjurious or helpful to good forestry during one stage of timber growth, and prohibitive of any forestry at all during the other. Research has shown, however, that grazing must be under control to be successfully used for the ends of forestry. Overgrazing on these semi-arid sites may destroy both forests and forage, thus not only rendering the land unproductive but creating a serious menace to the watershed and the irrigation interests dependent upon it.

Department of Agriculture estimates show that the 1,055 million acres of pasture land in 1920 contributed nearly as much to livestock production as all other agricultural crops combined. Nearly one-tenth of the nation's pasturage is forest land. The amount of research devoted to pasturage, and especially to forest pasturage, by all agencies combined has been entirely disproportionate to its relative importance to other forms of agriculture. This deficient knowledge of range management is particularly important because of the public interests directly involved. Owing to continued overgrazing, under the system of trial and error, the unreserved and unappropriated half of the public domain, for instance, is estimated to be producing only half its potential forage crop, and this deterioration is cumulative and hard to arrest. The rehabilitation of these semi-arid lands will be difficult enough, even after full knowledge of their ecology and of improved forms of range management becomes available.

The overgrazing of the public domain and of other intermingled lands has further resulted in a progressive deterioration of irrigation reservoirs by silting, and destruction of farm lands in river bottoms by floods, which is probably a far more serious loss than that of grazing values. This overgrazing is of many years' standing, and under the system of trial and error it seems to be correcting itself very slowly if at all, and with enormous economic losses. The only practical solution seems to be through research.

5. IS RESEARCH NECESSARY ON WILD LIFE AND RECREATION?

Wild life and recreation as secondary forest crops must usually be considered jointly, because a large part of the value of forest wild life lies in enhancing the recreational attractiveness of forest lands. This is not always the case, however. Fish culture and fur culture particularly may often be made the source of directly salable products, the revenue from which helps defray the current annual costs which otherwise are liable to become a heavy burden pending the maturity of the timber crop. In every case, game, fish, fur, miscellaneous wild life, water, and scenery add to the value of forest lands for recreation. In private forests they may render a direct return through the sale of recreational privileges, and in public forests their value from the standpoint of public welfare necessitates their careful management, regardless of whether or not they produce a monetary revenue.

There are two outstanding reasons for research in wild life: (1) It has heretofore been a wild or accidental crop, of the production of which

we have little or no knowledge; (2) without thorough knowledge of its place in the ecology of the forest, it is out of control. Without control, a species may be exterminated, and thus reduce the value of the forest, or another may become a pest and menace the forest or some secondary crop.

In the Lake States, for instance, one of the important enemies of white pine reproduction is the snowshoe rabbit. On the other hand, among the important recreational assets of the white pine forest are the white-tailed deer and the ruffed grouse. Yet it is asserted that the control of predatory animals and birds for the purpose of protecting the deer and the grouse is unduly encouraging the destructive rabbit and thus damaging the pine. Here is a four-sided problem in ecology, the answer to which we do not have but badly need. In all probability it will be found to have more than four sides by the time its various ramifications into parasites, diseases, and rodent cycles have been unravelled.

Again, in Arizona, on the Kaibab National Forest, the mule deer has become so abundant as to overgraze the range and threaten both range and deer with destruction. Immediately adjacent, in the Grand Canyon National Park, under a similar degree of protection, a valuable herd of mountain sheep is barely maintaining itself. Evidently we must rely upon research to find the reasons for such diverse effects if wild life resources are to be effectively conserved and controlled.

Still another reason adds urgency to the need for research in wild life problems especially by public research institutions. In Europe private ownership in game supplies an economic incentive to the development of a workable system of game management. In the United States wild game is in public ownership, and the economic incentive operates only indirectly through the private control of land. Experience has shown a dangerous lag between the depletion of valuable species and the inauguration of cultural operations by private land owners. If publicly supported research fails to provide foundations for a rational system of wild life management, it may in many instances come too late.

6. ARE INVESTIGATIONS OF FOREST PRODUCTS NECESSARY?

It is clear that every possible effort must be made by all agencies to grow as much timber as the productivity of our land and the growing capacity of our forest trees will permit and to get the timber-growing program under way as rapidly as possible. But it is also clear that our need for timber, because of its magnitude and urgency, cannot be met by timber-growing alone. It must be supplemented by vastly improved utilization. We must first, through improved utilization, make all the merchantable timber we now have, whether in virgin forests or second growth, go as far as it will. For upon forests already merchantable or those already started we must largely depend during the long lean years already beginning, until new and sufficiently large crops can be started and brought to usable size. This situation emphasizes all measures which will help to make better utilization a decided factor in the solution of our problem of timber supply, and specifically whether research can materially aid commercial trial and error responsive to economic forces alone.

Better utilization may be made also to aid in balancing our timber budget of the more distant future. The help that better utilization may

give can be stated in two ways which say practically the same thing. It may help by reducing the drain on the forest and hence the amount of timber it will be necessary to grow. It is estimated that we could save from 5 to 10 billion cubic feet of the total which is now wasted in manufacture and use. While we can probably grow under intensive management universally applied as much as 27 billion cubic feet annually, it will require many years to reach any such ideal. Second, better utilization may help to balance the timber budget by obtaining greater utility out of the timber which we actually take from the forest. With increasing population and industrial development we shall probably need more timber than now, and this probable trend must be weighed against the time which it will take to get an intensive timber-growing program under way on a national scale. A decisive advantage of better utilization is that technique once shown to be feasible and profitable can be introduced as rapidly as the inertia of manufacture and use can be overcome. Timber can be saved in a day which can be grown only in decades. These are additional reasons for speeding up better utilization through research if it is feasible.

Better utilization is of signal importance also in making timber growing profitable financially, particularly for the private owner, who now holds four-fifths of our forest land. Concretely it is the difference between being able to grow only pure stands of western white pine profitably in northern Idaho or of being able also to sell at good prices the low-priced western hemlock, western larch, and white fir which nearly always form a part and in many cases a major part of the stand. In an extreme case it will mean the difference between deriving returns from one-third of the standing forest or from all the species which make up the stand. Since we may have to depend upon the private landowner for as much as 80 per cent of our future timber supply we cannot afford to neglect any reasonable means which will encourage production, and possibly actual compulsion might be less potent than better utilization. The question is whether with these things at stake we can through research speed up the trial and error method sufficiently to make it worth while.

The best estimates available indicate that out of the total annual cut from the forest of 22½ billion cubic feet approximately 15 billion, or two-thirds, is lost in manufacture and use. Decay in manufacture, storage, and use is one conspicuous item of this total. Fully half of the 110 million railroad ties cut each year replace those which decay in service. Likewise one-fourth of the cut of piling timber, one-fifth of that of mining timber, 10 per cent of the pulpwood, in the neighborhood of 6 billion board feet of lumber, are needed for like replacements. This makes a grand total of more than 4 billion cubic feet by which the standing timber in the forest is reduced each year to render only a fraction of the service of which it is capable.

Woods operations in all kinds and sizes of timber deliver at the mill or corresponding stage of manufacture less by 5½ billion cubic feet than the volume of the standing timber. Only about half of the log that enters the mill emerges as a useful product, and mill losses add nearly 3 billion cubic feet to the total of waste. Seasoning, a single phase of lumber manufacture, is responsible, chiefly at the sawmill and remanufacturing plant, for a further drain on the forest of a billion cubic feet. Remanufacture of lumber into furniture, chairs, boxes, woodenware, etc., puts

into finished products less by half a billion cubic feet than enters the factories. These, together with a much larger number of miscellaneous small items, make up the aggregate loss of 15 billion cubic feet. The volume of our waste alone is nearly twice the 7.9 billion cubic feet required to supply European and Asiatic Russia, and nearly six times the 2.6 billion cubic feet utilized by Germany, the second and third countries in the world in wood consumption.

Even with full knowledge of the properties and behavior of wood and the most efficient technique of manufacture and use, some waste would be inevitable, but when we face a serious shortage of timber it is not good national economy to permit two out of every three forest trees to go this route. By treating railroad ties with preservatives and under processes already developed by research to prevent decay, we can easily increase to fifteen years the life of ties which would otherwise not last more than five. This for a single mile of track cuts the annual requirements from 528 to 176 ties. In one case, by better design developed by research in putting 13 per cent less lumber where it was needed for strength, it was possible to increase the strength of a shipping crate many times. Research has shown it feasible to reduce degrade in southern pine drying schedules from about 20 to 5 per cent in the upper grades and from 30 to 10 per cent or less in the common grades.

These examples indicate sufficiently the basis for an estimate that research results already obtained could, if combined with the best in current industrial practice, reduce the drain on the standing forest by about 5 billion cubic feet each year. When it is realized that the best in industrial practice is itself the result in part of research, one criterion is afforded of the value of research in better utilization. Another is afforded by a similar estimate that additional research could ultimately, if generally applied, double this saving and reduce the drain on the forest by a total of 10 billion cubic feet annually without the slightest reduction in its effective wood service. Much of this additional saving will depend upon a most intensive knowledge of the properties and behavior of wood, and this, because of the complexity of wood and the extreme difficulty in the determination of its properties, can be obtained only through intensive research.

The increasing scarcity of forests sets in motion economic forces which tend to lower the proportion of loss and waste. The competition of substitutes for wood tends to stimulate a better utilization of wood as a factor of efficiency. But the decreasing quality of forests and the increasing distance between forests and markets set in motion economic forces which directly raise the proportion of loss and waste. Economic forces often exist long before they are recognized. They are frequently blind and slow. There is thus no prompt and full remedy for the utilization of waste in the automatic operation of economic forces, although their pressure is on the whole gradually improving utilization and will so continue far into the future. Close utilization in Europe is the result in extreme cases of several centuries of economic pressure and of abundant and cheap labor. An extremely critical part of our utilization problem is one of decades rather than of centuries. And we can anticipate only high labor.

It seems certain from the few examples given that knowledge of wood and other products of the forest based on research can be made to expedite

enormously better utilization based solely on trial and error and the working of economic laws. It seems probable that only through research will it be possible to improve utilization rapidly and fully enough to become a vital factor in the solution of our problem of timber supply. Research is therefore as essential in better utilization as in any other phase of the forest problem.

Particularly during the past twenty or thirty years the competition of substitutes has been a material factor in reducing the consumption of such products as lumber or in absorbing increased demands which might otherwise have been filled largely by wood. For some of these purposes the substitutes undoubtedly have a superior utility considering only their properties and the requirements of the use. For others the properties of wood make it the better material. Price in either case might be a governing factor and the reduction of waste to a minimum might materially affect price. What we are likely to face in the future is a somewhat unstable, shifting market demand for competitive materials, with the outcome depending in part upon the relative amount of information available about each commodity, public understanding of this information, and prices. Through research other construction materials now probably have an advantage over wood in both knowledge of properties and utility, and in waste elimination. Wood has invaluable intrinsic properties but its full place in competition will depend in no small degree upon research.

7. IS RESEARCH NECESSARY IN FOREST ECONOMICS?

The forest industries occupy a commanding position in the economic structure of the United States. The capitalization in 1919 of a group consisting of lumber and its remanufacture, pulp and paper, naval stores, natural dye stuffs and extracts, and wood distillation, and excluding a much larger number of smaller industries which would not materially affect the total, exceeded $3,600,000,000. This total does not include stumpage and forest land, the value of which has been conservatively estimated at $10,000,000,000. The value of the output at the mill of this group reached practically $4,000,000,000 and it paid in wages nearly $1,100,000,000. These figures include manufacture only. While the number of industries which manufacture forest products is large, the number of consuming industries is far greater. Every industry, regardless of its nature, is a direct or indirect consumer of some one or more forest products, and this is literally true also of every person in the United States. To determine the bill paid by the ultimate consumer for these products of the forest the value at the mill should undoubtedly be multiplied by two or three; $10,000,000,000 might not be excessive. Some of the products like fuelwood, which accounts for approximately 40 per cent of our wood consumption, rarely appear in the tonnage reports of our railroads. Yet the total tonnage of products of the forest on American railways in 1923 exceeded 115½ million tons, which was roundly 9½ per cent of the total for all materials, and brought receipts of nearly $420,000,000.

These figures are matched by consumption of forest products equally impressive, totalling, as already indicated, nearly half that of the entire world.

We have therefore manufacturing, distributing, and consuming industries of vast size and greatest complexity which are interested in the forest

crop. The stability and in some cases the existence of these industries depends upon the permanence of the timber supplies. And while the forest crop can be renewed to insure such permanence, it takes from a minimum of 15 years for small-sized products to a century or more to grow the highest-grade materials such as clear lumber, veneers, etc., so that the time element is an important factor. In determining the value of economic research the question which we must decide is whether nationally, regionally, and by industries the better system would be to conduct this national forest and wood supply business plan-wise or to leave it to drift and opportunism and the blind play of economic forces.

If planwise, and of the wisdom of this there can be little doubt, we need far more reliable information than we now have on existing timber resources, on the potential volume which we can grow under systematic management, and on what our future requirements are likely to be. We have gone nearly as far as we can with the relatively meager data now available. These data, although they show a critical national situation demanding action along certain broad lines which are reasonably clear, are unsatisfactory in many respects. They are lacking in many of the most essential details. While we need as a basis for plans and policy, data obtained by uniformly conducted and systematic surveys of all forest regions in the entire country, we have only fragmentary, piecemeal surveys which have been made at different times under widely different plans.

Two specific examples will illustrate. A company manufacturing pulp and paper in New York can cut only one-fourth of its pulpwood requirements from its own lands. Many companies in the State are in fact in more serious straits. The State in 1920 imported from Canada 59 per cent of the spruce pulpwood consumed in its mills. Still further, the United States in 1922 met only 49 per cent of its total pulpwood needs from the cut of its own forests, supplementing annual imports of paper and pulp by approximately one million cords of Canadian pulpwood. The Canadians, however, have been giving serious consideration to measures which would hold this pulpwood for domestic manufacture. What policy should this company pursue? The State of New York? The pulp and paper industry? The United States? With nearly 470 million acres of forest land and 3,530 million cords of timber of the pulp species still remaining, is the United States helpless? How best find out? But this problem differs only in character and degree from those in other industries and forest regions and, as we approach timber bankruptcy more and more nearly, the number of instances of critical problems of current and future supply will increase.

Since four-fifths of our forest land is privately owned—and at best public acquisition of forest lands will increase very slowly—the national timber budget cannot be balanced without private forestry. Except in instances like manufactures of pulp and paper, where private owners grow timber in order to insure supplies of raw material for their manufacturing plants, private forestry will depend on profits from the timber growing operation itself. Experience has shown repeatedly that the point at which private forestry becomes profitable cannot be anticipated by private owners and seized as soon as it arrives. The possibility of profitable forestry existed in the white pine section of New England for thirty or forty years before it was generally recognized. The two big

forestry developments of recent years—southern pine and redwood—were discovered after they had apparently existed for some time. Such factors as the following indicate the possibility of profits: trends in demand for forest products; the exhaustion of existing timber supplies; wholesale and retail prices of forest products; stumpage prices of the standing timber, which may be the best criterion of returns in timber growing; and the probable costs of producing timber crops. Some of these factors are so complex or involve simultaneous observations in such wide fields that the individual owner does not keep currently posted and does not realize until years too late just when timber growing becomes profitable. An important object of research in forest economics is therefore to discover possibilities for profitable forestry as soon as they exist and to collect the experience of the entire country and focus it upon local conditions.

In general, therefore, the Federal Government, States, and all industries which manufacture, distribute, or consume wood or other forest products are now facing a rapidly growing need for intensive and authentic knowledge of timber supplies and timber requirements, and the entire range of fundamental and economic knowledge necessary to a sound public and business policy. Such questions as these have their only satisfactory solution in the collection, analysis, and interpretation of the underlying economic statistics. The task calls for skilled investigators, and, as in all of the phases of forest activities previously discussed, research offers the only reliable, thoroughly practical, and really effective method of attack.

8. IS THE FORMULATION OF A NATIONAL PROGRAM JUSTIFIED?

Detailed consideration of the main divisions of the forest problem leads, therefore, to exactly the same conclusion concerning the need for research as did general consideration of the forest problem as a whole. The inquiry by the committee into the need for research does not, however, stop here. The entire remaining discussion, of what we need to know in order to solve the forest problem, of the progress made in acquiring this knowledge, of the extent to which existing organizations must be strengthened or new organizations created, is in fact a continuation of the inquiry into the need for research.

The tendency has been to leave research for last consideration as a means toward national forest development. We rightly emphasize fire protection, for example, through national and numerous State programs. Public acquisition of forest lands finds expression also in equally numerous programs. But the fundamental basis for thoroughly effective fire protection and the foundation for thoroughly satisfactory management of forest lands once secured is left largely to the future.

We insist on timber growing by private owners but regard it as nonessential to inform them how, except in most general terms. We likewise insist that the industries eliminate all unnecessary wood waste, but we give them little information concerning how it may be done, and far too little of inspiration and leadership in ways of finding out. We assume that, because public opinion has of late swung strongly to forestry, it is an accomplished fact in the woods and mill. We overlook the lag between

public opinion and actual performance, and still more that one important reason for the lag is plain lack of information as to methods and technique, and that the lag will increase until research supplies the information upon which practice can alone be based.

Of all phases of the forestry question research is the most intangible and the most difficult to grasp, the most exacting in its requirements for men, the most time-consuming in the development of thoroughly effective organizations, and finally, the most difficult for which to obtain recognition and financial support. It will require the total efforts, on a vastly larger scale than anything now attempted, of every interested private and public agency in the United States to keep pace with the real need for information. These, therefore, are some of the considerations which point to the need for a national program in forest research. Before the opportunities and obligations of different agencies can be considered, it is neccessary to inquire into what research is necessary, and the extent to which it has been attempted.

THE RESEARCH PROBLEMS OF A NATIONAL PROGRAM

One of the first decisions which must be made in outlining research problems and progress in a national program is whether a discussion of fundamental problems only, or both fundamental and empirical problems, will be of greater present value in stimulating research.

Forest research in the United States is still in an early developmental stage. Much preliminary exploration has been and some will continue to be necessary as an aid and background in the formulation of the problems that should be studied intensively and fundamentally just as, in building, a scaffolding must ordinarily precede the final structure. The two classes of research merge. What seems to be fundamental today may not be so regarded in the light of tomorrow's findings. Many agencies in the United States which can undertake some work and should receive the utmost encouragement are not now prepared to attack the more fundamental problems.

The committee clearly recognizes that the trend of forest research must as a matter of efficiency and economy be as rapid as possible toward those fundamental problems which underlie all knowledge of forest growth and of all forest products and hence all forestry practice and timber utilization. But it believes that what is most needed at the present stage of our progress is as comprehensive an outline of the entire field of research as the time of the committee and present information will permit. In attempting this the committee believes that it is rendering the maximum service.

In making such an outline of forest research the committee is fully aware that the entire field cannot possibly be foreseen. The field is constantly broadening and new discoveries made at any time may radically modify the conception of special or even of general phases of the research program. Results will be obtained from time to time that will make very simple what now appears to be exceedingly complex. What appears to be very simple, on the other hand, may be shown by other research findings to be very complex. Obviously it is impossible within reasonable lengths to discuss in detail all the forest research problems which can now be foreseen. Those of greatest importance in the light of our present knowledge have therefore been covered in a suggestive rather than a detailed way.

Forest research must bring many sciences to its aid, as the following tabulation will show, sciences which cross and recross each other inextricably and which are almost exclusively subdivisions of biology, chemistry, physics, and economics:

Biology, of forest plant and animal life.
Botany, of forest vegetation.
Taxonomy, of forest trees, other forest plant life, forest and wood fungi, forest and wood insects, soil life, and the wild life of the forest.
Physiology, morphology, ontogeny, histology, cytology, particularly of forest trees, other important forest plants, poisonous plants, forest fungi and insects, and to a lesser extent of other plant and animal life of the forest.

Ecology, of forest types, subordinate plant associations, forest and wood fungi and insects, wild life, and of soil life.
Genetics, of forest trees and valuable forage plants.
Pathology, including fungi of forest trees, woods, important forage plants, soils.
Entomology, of forest trees, woods, important forage plants, soils.
Bacteriology, of soils.
Zoology, of wild life and soil fauna.
Geology, with particular relation to topography, forest soils, surface and underground water.
Soil science, the physics, chemistry and biology of soils.
Meteorology, in its relationships with the forest, subordinate vegetation, forest fungi, forest insects, wild life, domestic livestock, soil, streamflow, and forest fires.
Physics, of light, atmosphere, heat, and moisture, etc., in relation to the forests and forest vegetation; of soils, of the wood product, and of combustion in forest fires.
Chemistry, bio-, physical-, colloid-, organic-, and inorganic-, in varying degree of trees, wood, and other forest products and by-products such as forage, soils.
Economics, of forest land, of forest products, of forest administration, and of the forest industries.
Mathematics, forest volume, growth and yields, the strength properties of wood, forest economics, biometry in the application of statistical methods to many phases of research in forest biology.

Recognition of this overlapping of sciences in forest research and the complex relationship between them will greatly clarify an understanding of the discussion which follows. Furthermore, the complexity, running together, and overlapping, of the different phases of forest research discussed, and the resulting difficulty of drawing hard and fast lines between them, necessitate frequent cross references for clarity. This very necessity helps to drive home the essential unity of the entire forest problem and of the research which must so largely aid in its solution.

FOREST MANAGEMENT

Forest management is used in a somewhat restricted sense to include silvics, or the fundamental science which underlies the growing of forests, silviculture proper, or the actual growing of timber crops, and forest mensuration, or the determination of form, volume, growth, and yields. Forest management is therefore the sine qua non in the solution of the entire forest problem. It is the foundation on which all of the rest of the forest structure must be built.

The objectives of research in forest management become correspondingly important. The scientific basis must be supplied for the determination of the forest trees or mixtures which can best be grown under any set of conditions. The foundation must be furnished for an effective technique for reproducing forests both by natural processes following cutting and by planting. To insure the most rapid growth of material of the highest quality the basis must be supplied for the most effective cultural operations. A technique for brush disposal which will reduce the fire menace and aid in reproduction is essential. Good silviculture will go as far as practicable in reducing risks from fire and fungus and insect diseases. It will necessarily bear a close relationship to utilization and such other uses of the forest as livestock and game production. The foundation must

be laid for the determination of tree form, volume, and growth and for forest growth and yields.

Forest management has in common with agriculture the use of the soil in the production of plant life but is distinctive in the radically different character of the plant life, the time required to mature crops, and the nature and extent of possible cultivation. The relegation of timber growing by agricultural competition to the poorer soils and more remote situations, the piling up of production costs over years and even decades, and practical restrictions in cultural measures all serve to emphasize the need for taking the utmost direct and indirect advantage of the complicated biological relationships and balances which enter into the development of forest stands. Not only the trees but also all other forms of forest life are involved in greater or less degree in these relationships and balances. Research in forest management covers, therefore, a wide range of problems in the fundamental and applied biology of the growth of trees and forests and other forms of forest life. Its problems differ rather widely in their character and consequently in the technique necessary for their solution from those in any other biological research.

1. SILVICS

Silvics, or forest botany, like all other branches of biology, must in establishing the scientific foundation for silviculture begin with the taxonomy of forest trees, or dendrology. It must deal extensively with the life processes or physiology of trees and with the form and structure of their parts, or morphology. Ecology is probably of greater practical significance in the case of forests than in any other form of land use. The ontogeny or life histories of individual species, and likewise the development of tree associations or types, are closely related to ecology and hardly less important. Finally genetics has a place in the selection and use of geographical races of trees of superior form and growth, and in eliminating in many cases the use in artificial forestation of all except local races. Genetics has possibly an even greater importance in furnishing races immune from forest diseases and the possible development through tree breeding of much more rapidly growing and desirable trees.

DENDROLOGY

Linnaeus began the classification of American forest trees on an extensive scale, publishing his first results under the binomial system as early as 1753. This work has gone on more or less continuously ever since. With the exception of some hardwood genera, particularly those occurring in the southeastern United States, our tree species have been intensively studied by a large group of dendrologists and botanists, working independently and as representatives of many universities, botanical gardens and other institutions, of the various States, and of the Federal Government. A large amount of work is still under way by many institutions. The result is a substantial library of authoritative treatises on special groups or on the entire American arborescent flora, with Sargent's "Silva of North America" in 14 quarto volumes the outstanding work.

A good deal of work is still required on a number of southeastern

hardwood genera to raise them to the general level. This is true especially for such genera as the oaks, hickories, ashes, basswoods, and willows, about which there is still much difference of opinion, particularly regarding the definition of species and the proper classification. Many unanswered questions also exist regarding the classification of hybrids, where again the oaks present the outstanding difficulty. Different authorities ascribe different parentage to the same hybrids, and supposed hybrids have been located in regions which have later been found to be within the range of only one of the supposed parents. It is still uncertain whether some of the supposed hybrids may not be well-established species.

Important future work in the taxonomy of forest trees in the United States may be suggested by a possible tendency in past research on the part of some investigators to emphasize laboratory at the expense of field investigations. Both are obviously essential. Along with this has gone a tendency as with other forms of plant life to multiply the number of species upon minute and trivial differences in the form and structure of the flowers, fruit, leaves, and buds. The result has sometimes been to make the classification of tree species an end in itself without much or any reference to scientific or practical use in connection with the growing tree in the forest.

Although intensive laboratory studies will continue to be necessary, the most urgent work of the future is possibly a comprehensive series of field studies, particularly of such hardwood genera as those already mentioned, which will follow out on living trees in the forest the essential differences which have been worked out in the laboratory. The field study would ascertain whether the differences merge, and the extent to which apparently extreme forms in one part of the range gradually change into other apparently extreme forms in a different part. Such studies should among other things differentiate the simple, constant characters which may be depended upon in the field for the recognition of individual species. They should also clear up the question of races or barely distinct forms within species. And incidentally the question of hybrids already referred to would have to be settled. Such studies would of necessity add materially to our knowledge of distribution. In the end, within the more complex genera they might result in a regrouping into fewer species of closely related forms which would meet, far more satisfactorily than the present numerous species do, both scientific and practical requirements. Their essential basis might be field determination and use.

A distribution problem of great practical importance is whether the present ranges of our forest trees are in equilibrium. Existing distribution may not always be a reflection of present climatic and other environmental conditions. The Monterey pine and the Monterey cypress, for example, are limited in their natural distribution to extremely small areas on the coast of California. Both, however, thrive when planted outside their natural habitat, and the former has been established in Australia and New Zealand with such success as to be called the "Remarkable pine." Some foresters believe that the slash pine is a comparatively recent introduction in the South and is rapidly extending its range. Some evidence indicates that the hardwoods are gradually working their way northward in the Great Lakes region. There are some reasons to think that the high mountain spruce forests of the Southern Appalachians are slowly vanish-

ing remnants of characteristically northern forests formerly of much greater extent.

Investigations of changes in distribution now in process lead logically back into those of geological distribution or paleodendrology, which might easily afford a key to the understanding of present distribution of many species. The most significant of past geological disturbances was the glacial period, and no proper understanding of present tree distribution is possible without reference to its effects, together with those of the major swings of continental climate since that time. Differences in the rate of spread and conquest of tree species must also be taken into account. Such investigations might, for example, help to explain the very limited areas now occupied by the redwoods and several cypresses and pines in California. In general, a better understanding of changing distribution and of the geological background of existing distribution, independently or in connection with a better understanding of environmental requirements, might be of the greatest value in determining the possibility of extending the ranges of such valuable forest trees as those already mentioned. Greater knowledge of the evolutionary development of existing species would help also to bring out more clearly in many instances present taxonomic relationships.

Another large piece of taxonomic work which lies in the future is on shrubs and on those arborescent species which assume shrubby forms in some parts and tree forms in other parts of their ranges. Although they have received the attention of many investigators, upon the shrubs in general much less work has been done than upon the forest trees proper. But their importance as a part of the environmental make-up of forest types is being increasingly recognized as forest research develops. Much the same kind of work is called for here as that outlined for trees: pioneer work upon several genera such as Ceanothus, Rhus, Arctostaphylos, which form the chaparral stands of California and the southwestern United States, and upon the other genera which occur in the southern forests; intensive field investigations with the idea of scientific and practical field use constantly in mind; the regrouping of closely related forms into more easily usable species in such genera as Crataegus. Possibly out of this work also should come the beginning of a better understanding of the causes which lead species to assume shrubby or tree forms in different parts of their ranges.

PHYSIOLOGY AND MORPHOLOGY

No other single phase of the science underlying forestry is of greater importance than physiology. This is because physiology deals with the vital life processes of the tree which the forester must understand to make full use of them. Physiology deals with such processes as the functioning of the protoplasm and the activity of living cells in the cambium, leaves, and other parts of the tree. It deals with such processes as seed fertilization, production, and germination.

Investigations of physiology merge imperceptibly into morphology or the gross and minute form and structure of the tree parts for which the various life processes are directly responsible. Morphology deals with all tree parts, flowers, fruits, leaves, roots, and the wood itself, and with an infinite number of special adaptations of these parts for specific pur-

poses. Processes, parts, and structure must all be investigated in reference to the factors of environment with which there is the closest interrelation.

In tree morphology and physiology, or part and function, respectively, may frequently lie the key to many of the forester's problems. Knowledge on the one hand may afford the means to the production of healthy and vigorous trees and forests, of abundant and fertile seed and satisfactory regeneration, and of wood and other products in the desired quantity and quality. Lack of knowledge on the other hand may result in trees and forests of low vitality, scanty seed production and regeneration, and small production of undesirable products. It may mean non-resistance to disease and the resulting destruction of large parts of the forest. Probably many of the riddles of tree distribution such as the ability of trees to reproduce and thrive in the far north, and the ability to withstand extremes of heat and dryness, could be answered if we knew all the obscure and seemingly unimportant physiology of seed, seedling, and tree.

One important group of physiological problems involves the determination for different species of the form and quantities of food and other materials needed for satisfactory and optimum growth. Such requirements include carbon dioxide for carbon; water for its hydrogen and oxygen, and as a carrier of nutrient solutions containing various foods, such as compounds of nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron. The solar energy also required for growth will be considered later. We ought to know likewise about the materials which retard or inhibit growth.

A closely related group of problems requires the determination of how different species of trees use food materials. This group includes the absorption of water and nutrient materials, their transportation as a result of transpiration or otherwise, assimilation or photosynthesis and other elaboration into living protoplasm, cellulose, lignin, the extractives of the wood, and other tree parts. It includes the storage of various materials in different parts of the tree, and various changes in connection with storage and final use. This and the preceding group of problems concern essentially processes and the use of materials without particular regard to the part of the tree.

Another method of attack on physiological and morphological problems is to take up life processes, form, and structure of single parts or organs of the tree. For example, a group of such problems centers around tree seeds and includes fertilization, the subsequent development of seeds, the obscure chemical and physical changes which take place in seed stored under varying natural and artificial conditions, and finally, their germination. The delayed germination of the western white pine seed created difficulties in nursery practice for some time, and on the other hand in natural regeneration delayed germination has been found a very helpful factor. The Forest Service has found that the acorns of the eastern oaks show radical differences in seasonal and other requirements for germination which may also be physiological and which probably have an important bearing on the occurrence of the various species in the forest. Such things as the percentage of seed germination and survival, the relation of both to soil and forest litter, the ability of seeds to withstand cold, and delayed germination are undoubtedly related to the character and amount of food stored and perhaps to other physiological phenomena. Full knowledge

of the seed morphology and physiology of at least the important species may and probably will help enormously in obtaining more complete forest regeneration both natural and artificial, particularly where critical questions of obtaining new forests or of desirable mixtures of species exist.

Another large group of problems centers around root forms, processes, and development, a subject on which relatively little work has so far been done in the United States, but which if understood would in many cases influence our silviculture in a pronounced way. Soils are one of the most important factors in tree growth and as such will necessitate a comprehensive research program in themselves, but a full understanding of root physiology and morphology will be essential as a corollary to soil research. Among other things will be needed information for all of our tree species on root form, functioning, and development in relation to the physical and chemical composition of the soil, soil moisture and aeration, soil fauna and flora, symbiotic relationships, root competition, and root rots. The whole range of tree root development must be covered from germinating seedling to mature tree, and throughout the process of timber culture from nursery practice and artificial planting to the adaptations in silvicultural management under which the forest crop is grown, tended, and finally harvested and a new forest started.

The Forest Service has already found it necessary in the improvement of woods methods in naval stores production to study the formation, structure, and physiological functions of the resin tubes and their response to such a stimulus as the wounding of the tree. Maximum yields of naval stores depend upon the maximum formation and functioning of resin ducts. The effort at self-protection by the tree through the production of resin to cover wounds depends for one thing upon the frequency and depth of the chipping or wounding of the tree. The investigations which have attempted to get at these relationships have so far dealt mostly with structure or anatomy. Before they are completed it will undoubtedly be necessary to go into such questions as the nutrients required and the causes of vigor in tree growth and their relation to resin production, and, if present indications hold, the relation between resin flow and temperature and other climatic factors immediately following cupping.

Investigations of forms and life processes in seeds, roots, and resin ducts are merely illustrations, however, of the research which must eventually cover every part of the tree. Forest research must have as one ultimate purpose the production of the maximum quantity of wood and other useful products, but it must have as a second ultimate purpose the properties and the quality of the product as well. The key to a full understanding of many of the variable strength and other properties and much of the behavior of wood in shrinking, swelling, and checking, and hence to most forms of utilization, lies in a knowledge of either the physical or chemical properties of the wood or both. One method of attack must be through the chemistry of the wood and of its constituent parts, and microscopic and other studies of the physical structure, which will receive detailed consideration later. Another equally promising method is physiological and lies in an understanding of the synthesis of the wood in the living tree. Attacks by both methods will undoubtedly be necessary before the physical and chemical properties are fully understood.

One means of getting at the nature and causes of brashness in wood

may be through an understanding of the physiological processes under which wood is formed and of its minute physical structure. Brashness is one of the serious problems in the selection and use of woods such as the ashes and hickories, where strength and particularly toughness are required. Investigations of the ashes by the Forest Service have shown that to maintain the toughness of the young tree in the outer layers of wood, growing conditions must be such as at least to maintain the initial growth rate, and growing conditions undoubtedly affect the physical properties through the physiological processes. Still further, brash oak has also been found by the Forest Service to have a higher percentage of mineral matter and crystals than tough oak. The reasons may be partly physiological.

In time, unless they work out the problems for us, we shall undoubtedly want to follow more exhaustively the work of the European and Indian forest experiment stations in studies of the causes of and methods of preventing such phenomena as eccentric growth, twisted and crooked stems, heleotropism and geotropism, forms of growth which reduce the quality or the quantity of the final product or both. The relatively limited research in the United States, of which one study is that on knot zones and spiral grain by the New York State College of Forestry at Syracuse, supports the conclusion reached abroad, that difficulties of this kind may possibly be avoided by better cultural methods. Somewhat similar in character might be investigations of causes of spiral grain, which may seriously reduce the strength of timber for such purposes as aeroplanes.

Wood will in general be of greatest service when we know what given properties will most fully meet our requirements, within what stated limitations life processes can be depended upon to produce the desired properties, and under what specified limitations of conditions of growth the necessary physiological processes can be obtained. An understanding of tree physiology and morphology becomes, therefore, an essential means to the recognition and fullest feasible utilization of the growing conditions which will produce in the greatest quantity products of the most highly desirable properties and quality.

The grosser and more minute structure of wood might be discussed here, but it perhaps falls more logically under forest products and is accordingly taken up in that connection.

Normal physiological processes may be better understood if abnormal processes are known, and vice versa. The need for an understanding of morbid tree physiology permitting or resulting from the attack of fungus and insect diseases would in itself, as will appear later, justify the most searching experimentation. The key to an understanding of the epidemics of many insects may be found in the abnormal physiological conditions resulting from severe droughts, saturated soils, lack of soil aeration, or other abnormal phenomena.

The preceding are examples or indications of a very large group of the most fundamental problems of the greatest importance which ought to be attacked as rapidly as possible by a large number of agencies. Always there is the possibility that some discovery will revolutionize the entire conception of the life processes in plants and hence the technique and objectives of research.

When considered in the light of what is required, a brief survey makes the work done and that under way seem very fragmentary and inadequate. No one agency has even yet anything approaching a well-rounded-out program, and the aggregate program of all agencies together is but little better. Investigations at the University of Nebraska have determined the transpiration rates of both conifer and broadleaf forest seedlings, to obtain data on relative losses in summer and winter. The work of the Vermont Agricultural Experiment Station shows how difficult it is to get at the facts of transpiration when such relatively simple subjects as white pine seedlings are involved. The Carnegie Institution has worked out methods of measuring the growth of individual trees with the dendrograph and has shown the rate of response of Monterey pine to increased water and food supply. The Forest Service has done some work on the transpiration of seedlings of a number of western species. The Carnegie Institution has worked on water movement and food storage, and Cornell University on the translocation of food. Other work at Cornell indicates that cambial activity begins near the top of the tree and proceeds downward, and that the place at which growth first begins may be determined from the color of the bark. The University of Chicago has investigated the temperatures of pine leaves in winter.

The Yale Forest School has studied the initial root habit of some 150 species grown in nurseries and many western conifers grown under natural conditions, and has brought out facts of great importance for nursery practice and natural regeneration of the species studied. The seedling root development of a few species has been studied by the Forest Service with chief reference to the development of root hairs on such species as western white pine and the bearing of the location of these hairs upon the pruning of roots in nursery practice and upon subsequent field survival of planted seedlings. Syracuse University has investigated the relation between the beginning of root activity and diameter growth. The Carnegie Institution in numerous studies of the relation of aeration to root growth has shown that soil oxygen is necessary to proper growth and development of both root and top, and that one of the factors eliminating species from certain soils is the absence of soil air. The University of Illinois has found that the root growth of maple, basswood, oak, and hickory begins as early in the spring as the soil becomes warm enough for absorption and ceases when the soil becomes cold; also that when there is a summer resting period it is due to a decrease in water supply and not to any tendency towards periodicity. Investigators in the Carnegie Institution and the University of Nebraska have studied the root habits of many plants, including forest trees, in Nebraska and Colorado, to ascertain root relationships as an aid in the selection of sites for forestation. These investigations have been supplemented by the general observations and the research of many investigators upon plants other than trees, and an extensive literature is available.

Work by the Forest Service in Colorado and Utah has shown that cell sap density indicates the water requirements of forest trees and may be used as an index in correlating environmental factors with physiological response. Work by the Carnegie Institution and the Universities of Kansas and Minnesota shows that there is a close correlation between osmotic pressure of cell sap and soil moisture. Syracuse, Cornell, Maine, and

Idaho Universities have devoted some efforts to eccentric and spiral growths.

The structure of wood, in which there is no sharp dividing line between the growing tree and the product, has been studied extensively by Yale and the Forest Service, mostly in its grosser characteristics and for purposes of identification. The Forest Service has also studied the abnormal formation of resin ducts resulting from chipping in naval stores operations. Harvard University has investigated the anatomy of wood mostly in its bearing on physiology, pathology, identification, and properties and uses. More particularly the work has dealt with the cambium in its relation to growth, bordered pits in relation to ascent of sap and wood preservation, and the effect of spruce budworm infestations on the structure of the wood of spruce and balsam fir.

Apparently, therefore, most work has been done on wood structure, on roots, and on abnormal resin duct formation. Several pieces of work, excellent in themselves, have unfortunately been conducted with little or no reference to a forestry background. Considering the results so far obtained in the aggregate and the work under way, only the barest beginnings have been made and efforts have been so isolated and fragmentary that it is difficult even to generalize as to their value. Thoroughly comprehensive American research on forest tree physiology and morphology lies almost wholly in the future. With so limited a background of actual results it is difficult and unsatisfactory to attempt to place particular emphasis on any one or more of a group of problems which includes such things as: the character and kinds of food materials required by different trees; the manner in which these materials are used; the physiology and morphology of seeds, roots, and resin ducts; the physiology of wood formation and the relation of physiology to desirable properties of the product on one hand and to conditions of growth on the other; and normal and abnormal physiology in relation to such questions as protection against fungus and insect attacks.

ECOLOGY

Forest ecology is the relationship between the forest and its environment. The stand of forest trees represents the sum total of the influence of all contributing factors of soil, climate and light, other plant life, animal life, and topography. The influence is alike for no two species or combinations of species because of different physiological reactions to environmental factors by the trees themselves and because of competition between the forest species. An area which will produce the highest yield for a species of pine may be a mediocre site for a hardwood. The same area may vary from time to time as the soil deteriorates or any other conditions are modified by any cause whatsoever. The forester calls the aggregate of environmental influences the "quality of site." It is one of the most essential criteria in silvicultural practice, in the prediction of yields, and in plans for forest management.

Soil

The soil is one of the most important factors contributing to the forest environment. From the soil the tree derives mechanical support, all of the nutrient materials except carbon dioxide which are necessary to

sustain life and to permit growth, and all of the water needed for the transportation of these materials and for the maintenance of transpiration.

Agricultural soil science has developed rapidly in the United States in the last few years and has produced a considerable literature, but forest soils research is in its infancy even in Europe, where most has been done. The following discussion indicates in the most general terms some of the soil factors or problems which must be investigated, but only an incidental attempt is made to point out the exceedingly complex and important interrelationships between them.

Nearly all soil problems have their chemical, physical, and biotic aspects, the complexity of which is increased because they grade into each other imperceptibly, and because any one soil condition of importance to the growth of trees may be the result of combined chemical, physical, and biological causes. All soils problems must be investigated with reference to the physiological response of different species of trees. The response of the same species may vary at different stages in its progress from seed to maturity.

One important group of soil problems centers around the structure of the soil. What foresters need to know is the peculiar combination of mineral and inorganic constituents, of organic materials such as litter and humus, and of water and nutrient solutions which are most satisfactory for individual tree species and forest types in their different stages of development. They require also a knowledge of those conditions of soil structure which are unfavorable to growth. Obviously the size of mineral and inorganic particles is a factor in structure. The proportions of the various constituents may have a profound influence. There seems to be a whole group of colloidal conditions affecting structure which as yet are only imperfectly understood. Unsatisfactory conditions may result in the formation of a hardpan very injurious to satisfactory timber production, a question on which practically only one investigation, that of Yale University, has been undertaken in the United States.

Almost inseparably connected with structure is the composition of soils. It is well known that different agricultural plants vary greatly in the chemical compounds which they require for vigorous life, but our knowledge of tree requirements is very limited. Some compounds are toxic; others may serve as catalysts. Soil acidity is important. Here again what we need to know is first what mineral constituents are necessary for best growth of individual species, what the effect of different forms of these constituents is on their availability, and what other constituents are injurious.

The organic materials in the soil are the source of nitrates and incidentally also of mineral compounds previously used in plants and returned to the soil in conditions favorable for re-use. Forest management under many conditions results in a vast accumulation of organic material on or in the soil. European foresters have found it necessary to spend much time and effort on investigations of forest litter and humus, its influence in the raw and decomposed states on forest reproduction and on forest vegetation in general; but in the United States we have attempted little except in a purely incidental way. The important question of soil acidity is involved here also.

Water is an important factor in soil composition as well as in structure,

and presents another group of important problems. Soil water occurs in such radically different forms, in chemical combination and in the colloidal, capillary, and free states, in each of which availability to various trees is undoubtedly different, that the determination of availability is complicated and difficult in itself. Excess water accumulation in swamps of various types, such as sphagnum and those flooded periodically from streams, extends still further the range of this group of problems. Nutrient solutions in a way express a resultant of many factors of soil structure, organic and inorganic composition, and water relations. Their importance is indicated by the fact that all plant food except carbon dioxide enters the tree solely in this form.

Possibly a little more work has been done in the United States on soil aeration than that on most other forest soil problems. Investigations of the Carnegie Institution, for example, have shown that the roots of willow will continue to grow practically without oxygen, whereas other tree species require relatively large amounts. The Carnegie Institution has also devoted some time to investigations of the influence of aeration upon root development and functioning of the redwood. Climate and light through precipitation, temperatures, and radiation are also among the factors which influence soils in important ways.

Soils teem with microscopic life. The insects, earthworms, and other forms visible to the naked eye are in reality only an infinitesimal part of a population which fluctuates widely in numbers even from hour to hour. Fungi, the numbers of which run into the hundreds of thousands per gram of soil, have one important function in the decomposition of cellulose into humus. Some mycorrhyzae may aid tree growth, although work by the University of Illinois indicates that the mycorrhyzae on seedlings of northern white pine may at times be a detriment to root functioning and development. Bacteria may exist by the score or more of millions to the gram of soil. Some of them are known to break down the derivatives from the decay of the forest litter and to make nitrates available for plant use. Others exist in the root nodules of legumes such as locust and contribute to tree life through the fixation of free nitrogen. A study by the Forest Service has shown that nitrogen bacteria on the lupine has a decidedly beneficial effect in stimulating the growth of pines on cut-over lands in California. Still other bacteria may produce injurious substances or themselves assimilate nitrates which might otherwise be available to trees. The numbers of protozoa range up to one million per gram of soil, with some indication of a relationship between their numbers and those of bacteria. Knowledge of the way that the primitive soil algae fit into soil life is still lacking. Even the investigations of the fauna and flora of agricultural soils is still in its infancy, and much less has been done on forest soils. The pure biology of most forms of soil life still remains to be studied. Even the technique must be worked out and this involves great difficulties. Finally, we must learn the relationships of the various species to the development of the tree and the forest. From such information will undoubtedly come the explanation of many phenomena now obscure; for example, the inability for several years to reforest areas in which suddenly and without apparent cause renewed efforts succeed. Out of it will unquestionably arise many special adaptations of forest management. Here alone is a problem or rather a group of problems for

years of most valuable work by many men and organizations in the United States.

Practically all forests contain associations of subordinate vegetation, shrubs, herbs, and grasses, as a part of the more comprehensive forest association. The subordinate vegetation undoubtedly influences the soil factors in innumerable ways and through them tree reproduction and growth, and in turn is equally susceptible to the soil conditions as influenced by the forest cover. This interrelationship must, therefore, be taken into account in all forest soils research.

Fire exercises an important but largely unknown influence, possibly on the soil directly, and without doubt indirectly through the soil life, the forest and subordinate vegetation, and the forest litter and humus. Soil changes are undoubtedly important factors in the vegetative succession which seems to be necessary in some cases following fires before the forests can again be grown, as for example in the brush or chaparral and forest succession in California. As yet but few attempts have been made to find out just what these fire influences are. One by the Forest Service is on the effect of fire on soil nitrates and erosion. Yet fires run over millions of acres of forest land each year and the silviculturist now faces his problems of forest renewal in utter ignorance of their effect on soils and their bearing on silvicultural technique.

Forest nurseries in their soil problems are more closely allied to agriculture than any other phase of timber growing. There is the same opportunity for cultivation, fertilization, irrigation, and manipulation in general, but forest tree requirements differ from those of any farm crops. Special research is therefore required, and on this phase of forest soil research quite a number of forest organizations in the United States have worked.

All of the soil factors in widely varying combinations make up forest soil fertility, which differs for each tree species. We ought to have criteria for judging fertility accurately. We ought also to know how to maintain fertility under different conditions. The experience in German forests, where productivity has been reduced by repeated cropping in pure stands of the same species, must be avoided. We should be able to recognize the warning signs of decreasing soil fertility. In Europe the question of increasing the fertility of forest soils appears in the programs of many forest experiment stations, and we may face the need for similar work here.

The forester must be able to interpret knowledge of all the soil factors, for the different species of trees and combinations which he attempts to grow. He must know how to take the fullest possible advantage of all the factors individually and of their sum or forest soil fertility, in artificial forestation, in the selection of methods of cutting, in attempts to influence the composition of the new stand, and in short in the whole field of forest management and protection. While the forester cannot cultivate the soil except in the nursery, he can, through the use of the ax in cutting the timber and through the planting spade, the disposal of brush, the regulation of livestock grazing, and the prevention or use of fire give free play to natural forces. Dependence on relatively indirect methods makes the need as great as or even greater than in agriculture for the knowledge which only the most intensive research can supply.

Most forest soil investigations in the United States have dealt with

nursery practice and have been largely of an empirical character, such as the trial of different fertilizers, and the checking of the results on the seedlings produced. Nearly all agencies which have grown forest nursery stock have attempted something of this kind more or less systematically.

Next in volume are investigations of the relation of soils to forest trees and types, reproduction and distribution, wherein the University of Chicago has worked on the sand dunes of the Lake States and on the Mississippi bottomlands, the University of Illinois on the central hardwood types, Syracuse University on several Adirondack types, the Carnegie Institution on the cypress swamps of Florida with particular reference to salinity, the Massachusetts and Connecticut Agricultural Colleges on the types of their respective States, Harvard University in cooperation with the Forest Service on pine soils and reproduction in the Northeast, and the Forest Service independently or in cooperation with the Bureau of Soils on a number of southern and western types.

The importance of soil acidity has been indicated by the work of the Bureau of Chemistry on 23 conifers, which shows that most conifers prefer an acid soil. Work by the Bureau of Chemistry indicates also that when the humus layer has been destroyed or altered by exposure to light incident to the cutting of the stand or to fire, the chemical character of the surface soil has a very important influence in determining the character of new growth and whether efforts to reproduce the former forest are likely to succeed. The Forest Service has investigated the effect of soil acidity and alkalinity, soil temperature and soil moisture, and the availability of soil moisture for a considerable number of western types. Research by the University of Wisconsin indicates that the high water capacity of peat and peat soils is a factor of great importance in preventing proper aeration, and also that the activity of nitrifying bacteria is almost completely inhibited in natural bog soils owing to acidity, deficiency in oxygen, and low temperatures. Work by the Universities of Washington and Minnesota has shown marked reduction in the growth of trees such as Douglas fir, western hemlock, lodgepole pine, and red and black spruce in swamps. A cooperative investigation is now being made by the University of Minnesota, the Bureau of Public Roads, and the Forest Service on the effect of swamp water and partial drainage in the Lake States. Work by the University of Nebraska has shown that very deep extensive root systems are a response to deep soil moisture in the time of drought. Investigations of the Forest Service have determined the relative water requirements of seedlings of several forest trees. Research of the University of Chicago on the sand dunes of the Lake States has shown that the rate of evaporation into the atmosphere and the amount of growth water in the various dune associations vary directly with the order of succession from plant to tree associations. Work by the University of Chicago has also shown that attempts to introduce plants and trees on the dunes should take into account their reaction to the organic matter in the soil. Studies by the Idaho Agricultural Experiment Station indicate that the forest litter from various local trees are toxic to nitrogen-fixing organisms such as azotobacter. The Maryland State Forest Service has studied the effect of the removal of forest litter on fertility and the Forest Service is now investigating the fertilizer value of forest litter in

the Lake States. The Wisconsin Agricultural Experiment Station has shown that the extent to which soil is frozen may directly retard growth or limit the size and distribution of trees. The Vermont Agricultural Experiment Station and the Carnegie Institution have each worked on soil moisture and temperature for two species. Cornell University has investigated hydrogen ions and seed germination. The Yale Forest School has studied the formation of hardpan in relation to surface soils and its effect on forest growth.

The preceding references to work done or now under way are incomplete, but it is obvious that valuable though many individual pieces of work are they constitute only the barest beginning of a real understanding of our forest soil problem in the broad sense. So little, in fact, has been done on this problem that it is difficult to say which phases are of outstanding importance for future work. It may be found that varying emphasis will be necessary in different parts of the United States. The forest litter and humus problem in the spruce stands of the Northeast, in which the duff accumulates to a great depth, may for example be very different in importance and urgency from that in southern pine stands, where leaves and other forest débris seem to disappear entirely in the course of three or four years.

What we want for each forest and soil type is knowledge of conditions which are favorable or unfavorable to most satisfactory timber growth, whether it involves soil structure, mineral or inorganic composition, acidity or alkalinity, nutrient solutions, soil life, aeration, or other things. We need to know how to avoid unfavorable soil conditions and to bring about the most favorable conditions by the use or prevention of fire, the disposal of slash following logging, the density and composition of forest and subordinate vegetation, and by any other means at the forester's disposal.

Climate

Although the soil supplies water and all of the nutritive materials except carbon dioxide, the sun transmits in luminous and other rays the vital force necessary to the life processes of the tree. The energy of the sun also dominates the climatic environment of the tree through air temperatures, precipitation and wind. Climatic factors as a group, therefore, rank with soil in their influence on forest distribution, reproduction, and growth, and possibly also on the strength and other properties of the final product—wood.

Leaving light for later consideration, meteorological research is needed in forestry for three rather distinct purposes, forest protection, distribution and growth. Together they require a thorough overhauling of existing climatic data, the installation of many additional stations especially in the more inaccessible forest regions and types, where up to the present time there have been relatively few, and additional observations on humidity and evaporation, and other conditions now only infrequently measured.

Forest protection, the first purpose, requires a thorough understanding of current weather conditions and their influence on fires and forest insects. This is taken up in detail in the special program outlined for forest protection.

Any study of the distribution of individual species, the second pur-

pose, leads inevitably to a study of the climatic environment which must largely control such distribution. We need to understand for each species, and sometimes for races within species, the particular climatic conditions which limit distribution. It may, for example, be the late spring or early fall frosts which investigations of the Forest Service have shown to rule most of the eastern hardwoods out of the western mountain ranges. It may be the annual precipitation or its uneven distribution, with long periods of drought during critical vegetative periods, that finally makes impossible the extension of the range of a species. It may be the length of the growing season, or the lack of sufficient heat units in the summer singly or with other factors, as shown by the work of the Forest Service and the Carnegie Institution. It may be the low temperatures or fog or rain at the time of flowering which make fertilization impossible. To be of the greatest value the why of the inhibition should also be known. The importance of climate should not be stressed to the exclusion of the part played by the physiological processes or by the soil, but the study of all should go hand in hand.

The third purpose of meteorological investigations is to determine the relation of climate to forest growth. Although intimately related to distribution, the influence of climate on growth is really distinct, since it does not necessarily follow that a factor which controls reproduction closely will sharply limit the growth rate or the ultimate size and form of forest trees. The more fundamental phases of the study have to do with a thorough understanding for all species of the climatic factors which affect growth, and of their relationship to soil factors and to the physiological processes of the tree itself. We need to know for each species the optimum climatic factors of diurnal, seasonal, and annual temperature, of the amount, form, and distribution of precipitation, of atmospheric humidity, which will insure maximum yields. We need to know also how far removed variations need be to reduce growth seriously or to result in shrubby forms which have no commercial value.

A knowledge of the requirements of species with reference to climate already enters into the solution of a number of problems, such as the causes for the absence of natural reproduction in certain forest types; the probable success of planting under such circumstances; and the choice of species for extensive reforestation projects where not clearly indicated by evidence on the ground, as for instance in the practically treeless sand hills of Nebraska.

Another phase of this question, which is already becoming large, is the development of climatic varieties of species and the extent to which they must be recognized in the interchange of seeds and plants between regions. This critical question for such widely extended types as the western yellow pine, Douglas fir, and some of the southern pines is being studied by the Forest Service. Knowledge of wind movement and the susceptibility of various species to windfall is an important consideration in silvicultural cuttings. Snow and sleet breakage will have a marked effect upon the mixture of species and also upon the methods of cutting and thinning.

Research in the United States on climate as a phase of forest environment has included work by the Yale Forest School on temperature as affecting seedlings; it has included a comprehensive investigation by the

Forest Service over a period of several years on most climatic factors in relation to the distribution and growth of the more important western species; and similar work in southern Arizona by the Carnegie Institution. The Missouri Agricultural Experiment Station has shown the seasonal relationship of the growth of oak, chiefly in height, to precipitation; the Carnegie Institution that of the redwood and Monterey pines to both temperature and precipitation. A large number of agencies have investigated such questions as frost heaving of seedlings. The Biological Survey has studied life zones including the forests, chiefly in the West. Even in the West, where the fullest data are available, we are only beginning to understand the climatic relationships, and years of work involving a vast amount of detail are still necessary. For the East much less has been attempted. A cooperative investigation has been made by several organizations of forest types and climate on Mt. Marcy. The Illinois Normal School and the Weather Bureau have studied forest environment in southern Illinois, and the Yale, Harvard, and Minnesota Forest Schools have done some work in their respective localities. An invaluable basis for studies of climatic requirements of tree species has been laid all over the United States by the Weather Bureau through the collection for general purposes of an enormous volume of detailed climatic data over a period of many years.

The justification for a separate discussion of light, or rather solar radiation, is that it constitutes the *sine qua non* of all productive plant growth. It is disturbing, therefore, to find that the light relationships of trees have been studied so little and with such inconclusive results. For many years foresters have attempted to differentiate species of trees according to their tolerance of shade, and of their light requirements for optimum development. Clear-cut experimental results on this problem are still essentially lacking, however, and in a major portion of all the evidence we find tolerance of shade and tolerance of root competition badly confused. Clearly there is need for a complete cataloging of all the important forest trees, with respect to such factors as the following:

The optimum intensity of light or radiant energy for maximum tree growth.

The extent to which growth is reduced by intensities above or below the optimum.

The minimum requirements for sustained existence.

The determination of the most effective wave lengths.

The relationship between light or radiant energy of various intensities and the chemical, physical, and biological qualities of different soils, other environmental conditions, and the physiological activities of the tree.

Similar environmental and physiological relationships to various wave lengths.

As a matter of fact, although much work has been undertaken in recent years on many plants, there is as yet no complete and systematic body of knowledge such as is contemplated above on any group of plants and much less on trees. Investigations to date on light in relation to forest trees have included several years' work at the Vermont Agricultural Experiment Station on the light requirements of a limited number of species, the relative efficiency of various light rays, and of discontinuous light. The investigations of the Vermont Station show that differences

in size and that minor differences in chemical composition of white pine seedlings grown under different degrees of shade must be looked for in photosynthesis rather than in absorption and transpiration. Johns Hopkins University has studied light intensity and transpiration; the Yale Forest School has made field measurements of light intensity; and the Forest Service has looked into the requirements in light intensity of a limited number of species in seedling form.

It practically goes without saying that if the silviculture of a century or more has been built up around a conception so unsubstantially founded as the existing conception of variation between species in shade tolerance, sound knowledge on this subject cannot fail to have bearings of the greatest importance. The conception affects the treatment of seedlings in the nursery. It bears upon the whole natural process known as the succession of species and consequently upon artificial changes such as the underplanting of forests when they reach a certain age and upon cuttings to encourage natural reproduction of one species or another. Light as affected by density of stands is assumed to play a major rôle in the development of the form of trees, their clearness or freedom from limbs and knots, and consequently the value of their wood. The density, the strength and other physical properties of wood are probably affected by the presence or absence of optimum light conditions. Finally, we may readily imagine that variations in the quality of light utilized by different species has a strong bearing on the association of two or more species, especially where moisture is not a limiting factor, and that through effective selection and mixing of species the vigor and total productivity of the forest may be greatly increased and the danger of serious insect and other attacks greatly reduced.

Investigations such as these involve so many different tree species, and the interrelation of other climatic and physiological factors with light is so evident that it is hopeless to expect that the problem can be solved or even very thoroughly defined by investigations such as those already undertaken or without adequate apparatus, equipment, and control of environment. The extent to which preparations must go to be effective may be indicated by the equipment of the Boyce Thompson Institute for Plant Research. Work in the laboratory, however, to be at all satisfactory and complete must be checked, supplemented and rounded out in the forest itself. Until it has we cannot be sure that we have not in the laboratory set up conditions which do not correspond at all with the conditions in the forest which we are attempting to measure.

Fires, Insects, Disease, and Animal Life

Forest fires, insects, and fungus diseases, factors of greatest importance in the forest environment, are discussed under Forest Protection. Animal life is discussed under Wild Life.

Subordinate Vegetation

The shrubs, herbs, and grasses of the subordinate forest vegetation which form a more or less complete cover under the tree canopy are an expression of soil, climate, and other growth conditions. Since the subordinate vegetation influences the forest cover, it must along with soils and climate be recognized as a factor in the forest tree environment.

Before we can have the most effective silviculture, we must learn for all of our many diffrent tree species and forest types the effect of the subordinate cover in all of its variations on such things as natural reproduction, planting, and forest fires. We must also learn its effect on soil moisture, structure, composition and life, and on the composition and rate of decomposition of the leaf litter. Incidentally this will involve a good deal of work in all parts of the United States on the subordinate cover itself, its composition, associations, successions, soil and other requirements, and, finally, on how it is affected by the forest.

Only when this information is available shall we be in a position to control the subordinate cover, to take advantage of it in such ways as to further timber growing, and to use it directly to the maximum for livestock and game grazing.

It should be possible to use single plant species or groups of species as indicators of soil fertility and of site conditions, of excessive acidity, or of undesirable humus conditions which can then be remedied by proper silvicultural measures. It has been found by the Forest Service in the California pine forests that, if cutting opens the forest too much, brush will come in, and that brush frequently retards the establishment of pine reproduction, sometimes for long periods. In the East, the work of the Forest Service has indicated that undergrowth of brush, vines, and cane in swamps is a distinct hindrance to reproduction of the southern white cedar which demands considerable light. Knowledge of this relationship between brush cover and reproduction is necessary to the forester in order to favor the forest in its life and death struggle with the brush. Out of this work will eventually come also striking recognition of the vital place in forest management of many shrubs and plants which heretofore we have commonly regarded as worthless or even as a nuisance. Work of the University of Minnesota has indicated that the succession of grasses and shrubs in the subordinate cover in the Nebraska sandhills may even pave the way for the establishment of a forest cover.

Chaparral, which partakes of the character of both brush and forest, presents a somewhat different problem. Because of its influence on streamflow and irrigation water and particularly on erosion in a region of most intensive agriculture in California, it is necessary to look forward to a form of chaparral management which will best meet agricultural needs. Only a bare beginning has so far been made in obtaining the scientific foundation for management of this character.

As will appear later in the discussion of forest range investigations, most of the investigative work on the subordinate forest vegetation has been done by botanists working along purely ecological lines or by investigators of forest range management. But relatively little of it has been done with particular reference to the timber growing relationships. Next in volume possibly should be placed investigations of chaparral and brush in California by the University of California, Stanford University, the Forest Service, and the Carnegie Institution, some of which have had either forest or chaparral management as an ultimate objective. Nearly all other investigations of the subordinate forest vegetation have been incidental to other research and fragmentary in character.

Regardless of whether the final objective is forestry or livestock or game grazing or watershed control, investigations of the subordinate cover

have much in common, and much would be gained if this could be recognized. Furthermore, if there is to be unity of purpose in forest management and all forms of utilization are to be correlated parts of a larger whole, this must be reflected in the character of any research undertaken on the subordinate cover regardless of its ultimate purpose.

Topography

Topography introduces still another set of varied factors into the forest environment or quality of site complex, with which at present we have a valuable but only a rather general observational acquaintance so far as the trees of the United States are concerned, and an extremely limited number of more intensive investigations.

Mountains and valleys control wind direction and movement, are responsible for profound changes in temperature and precipitation, and frequently dominate the distribution and numbers of the electrical storms which are such an important element in setting forest fires. Likewise altitude, distance from the sea, etc. bring the same and other influences into play. Topography may in fact dominate local climates. Both aspect and degree of slope have important light and heat relationships. Aspect in its extremes of northeast and southwest is frequently responsible in the western mountains for absolutely different forests, in species, types, growth, and forest conditions in general, within very short distances; and still further over a large territory it is responsible for the presence of a forest in one case and its entire absence in the other. The degree of slope exerts still different influences in run-off, and other factors.

Some of the problems which grow out of topography are world-wide and involve the determination of general laws. Most are local as to species, forest types, soils, climate, etc. Altogether for a continental area such as the United States the number of additional problems introduced and of complicating factors brought into play is very large.

General observational work on topographical influences has been done by all research agencies. The most detailed work is that of the Forest Service. It was undertaken as a part of the investigation of forest distribution and growth and climate in the western white pine forests of northern Idaho, and the mixed coniferous forests of northern California, the Southwest, and the Central Rocky Mountain region. Among other things these studies indicate that while the lack of precipitation and high evaporation are the determining factors at lower elevations, the upper limits of a tree's range are largely determined by low temperatures. Although comprehensive in themselves, these studies are only a bare beginning to the work which will ultimately be necessary.

ONTOGENY

Essential to the practice of forestry are the life histories or ontogeny of all the important tree species and probably in the end most or all of those now considered unimportant. While the complete history in each case will consist in part of the summation of the results from other investigations undertaken for other purposes, the gaps must be filled by supplemental research. In a way, therefore, this series of investigations cuts across or overlaps many of the lines of work already discussed and those

which will be taken up later, but it rounds them out in a most desirable and necessary way for the forester's needs.

Whatever the source, the results must include the entire life story of the tree from the germination of the seed through seedling, sapling, and tree development, completing the circle with the production of seed crops. Soil, climatic, and light rquirements from the juvenile stages to maturity, the effects of plant association, susceptibility to fire injury and to fungus and insect attack, must all be covered.

The life histories of forest types are similar in detail but broader in scope than those of individual species. They will likewise consist in part of a compilation of results from other investigations and of the necessary additional investigations into the origin and development of forest types, and the association and competition between their species.

Where types consist of a single species, the life histories of species and type will be similar in many respects. Where there are two or more species, however, each will differ in reproduction, growth, and reaction to common factors and to each other. Competition between species may be of great significance. Very often the apparently single species type, such as the Douglas fir type of the Pacific Coast, is in fact merely a phase in succession, since the Douglas fir drops out with increasing age and is slowly replaced by such other species as western hemlock and cedar. Many examples of the succession of temporary types in the development of a final or climax type occur in the United States and must be fully understood for the effective handling of the forest. It is well within the range of possibilities, for instance, that the owner may want to grow hemlock for pulpwood, instead of Douglas fir for saw timber, so the problem may be to perpetuate in actual forest management any desired phase in type succession.

As previously indicated the southern slash pine may illustrate a relatively recent and very desirable introduction capable of extending its range competition with other species which now make up the forest. The coast redwood may be a very ancient survival with some reason to believe that the present distribution is in part accidental. A full understanding of the life histories and the requirements of these trees and of the history and requirements of the forest types in the surrounding territory may enable the forester greatly to extend the range of such species.

The life histories of species and of types must, in short, include all that the forester ought to know of both as a basis for scientific forest culture. The number of life histories of individual tree species already published probably exceeds 50 and represents the contributions of several State organizations and universities and of the Forest Service. All are of value and contain what was known at the time they were prepared. Many deal with the most important single species in a type. Since none is thoroughly satisfactory and in fact could not be in the existing status of our fundamental knowledge, all require much additional work. On a very much larger number of species nothing has been attempted.

Of type histories already prepared the number is much smaller, about 12 in all, the work of the agencies indicated in the preceding paragraph. Many attempt to cover only a part of the life period, such as natural

reproduction. Their practical value and correspondingly the need for them is even greater than for species histories.

GENETICS

Pronounced differences between individual trees, under seemingly identical environmental conditions, are fairly well known. Differences have been recognized in rate of growth and the period during which growth continues; the amount of seed produced and the age at which seed-bearing begins; immunity or resistance to insect attack; the amount produced of such products as resin; and the strength, durability and other properties of the wood. For many years distinct "races" of spruces, pines and firs within the same species but originating under different environmental conditions, have been well recognized in European forestry. Of races within species the United States has examples in the large, rapidly growing, moisture-loving Douglas fir on the Pacific Coast, and the much smaller, slow-growing form of the comparatively arid Rocky Mountains; the rapid-growing, relatively large, borer- and decay-resistant yellow locust as contrasted with the smaller, susceptible black locust of the same species; and the western yellow pine with several races varying in the extreme from the small Black Hills type to that of the California Sierras.

Most of the work done in the United States in the development of better strains of trees or the utilization of superior races has been confined to the collection of seed of the same species under widely different conditions and the planting and close observation of the seedlings in a number of localities. This has been done by the Forest Service for a relatively small number of the more valuable western conifers and southern pines and by some eastern States and institutions for a relatively few eastern species. For example, in northern Idaho tests by the Forest Service of western yellow pine stock obtained from 16 different localities in the West showed that the local pine had become adapted to local growing conditions while stock from other localities, although superior in rate of growth, suffered from late spring and early fall frosts and winter killing. The Forest Service also has plantations in the Pacific Northwest of seed from selected Douglas fir trees of rapid growth and similar tests for western yellow pine in the Central Rocky Mountains. Investigations of the same character have gone much further in Europe, chiefly through plans developed by the International Association of Forest Experiment Stations. The New York Botanic Garden is reported to have worked on the development of a more rapidly growing aspen for pulpwood purposes. Very recently the Eddy Tree Breeding Institute has been established in California and promises a thoroughly comprehensive investigation over a long period of years into the possibility of developing more desirable trees.

Hybridization may afford opportunities. One hybrid that has attracted attention on account of its exceptionally rapid growth is the so-called "Norway poplar." This tree is supposed to have been produced in Europe by the accidental crossing of a European-grown form of one of our eastern cottonwoods and the European poplar (*Populus nigra*). On well-drained, moist, moderately fertile soils the height and diameter growth is reported to exceed those of any of our native cottonwoods, some of which are noted for rapid growth. One hybrid walnut (*Juglans regia* and *J. californica*) is said to grow faster than the combined growth of both its parents. These examples, which may not hold out under continuous

production, are cited merely as an indication of possibilities. Hybridization is a field in which practically no work has been done.

Such wonderful progress has been made in the breeding of improved livestock, of improved strains of a large number of agricultural crops, and of improved fruits that it ought to be possible to take advantage of the apparently large variation among individual forest trees to bring great improvements over the average forest-grown tree of the present time. It should be possible to recognize and to extend the range of superior races from the standpoint of growth, form, or other desirable qualities which have developed naturally. The possibility of finding or developing strains or races immune from the attack of various fungus diseases or forest insects justifies a large amount of work in itself. The entire question of forest tree genetics should, therefore, be investigated in the most fundamental way. This is the more essential because forest trees ordinarily begin to bear seed at a relatively advanced age, are still older before they begin to bear abundantly, and require such a long period for growing timber of merchantable size, at least for high-grade products such as lumber; and finally because insect and fungus attacks may be very destructive and exceedingly difficult to control.

The extent to which superior or improved races or disease-immune strains can be used constitutes another problem. One obvious use would be in artificial forestation. Possibly practical use could not much exceed this because of crossing with other stock and deterioration in natural regeneration. A better understanding of tree genetics might however be made gradually to improve the forests through a better selection of seed trees and through more intelligent removals of undesirable trees in cultural operations.

2. SILVICULTURE

Research in silviculture includes primarily the applied investigations which lie between fundamental findings in silvics and the commercial practice of forestry. It illustrates the supplemental research which is commonly necessary to fill the gap between the findings in fundamental research and the possibility of their practical application.

The question of what forest species or mixtures should be grown under specified conditions is the first which should be answered in silvicultural research. It may be found advisable to try to reproduce the species of the original stand. If, however, an attempt is made to improve upon or depart from the original stand it will be necessary to take fully into account all environmental factors such as soils and climate as well as the habits and requirements of the tree or mixtures which are to be used. The element of protection against fungus or insect attack may be important in indicating the mixtures which will ordinarily be more resistant. The possibility of a higher quality of timber in mixed forests is indicated by investigations of Harvard University. Mixed forests in which eastern white pine was one species were found to result in smaller knots and higher quality lumber. In determining upon the species which should be grown the intrinsic value of the wood must be taken into account, as must also past, current, and probable future market values. Altogether a good deal of supplemental research may be advisable as a basis for a decision on the trees to be grown. This is all the more necessary because

mistakes once made cannot ordinarily be corrected for many years and may be very costly.

Following the scientific basis for a decision on the species which should be grown under specific sets of conditions, a series of questions for research remains on how to reproduce the forest and how by a series of thinnings and other cultural operations to bring it to maturity. The various operations required should not be regarded as distinct, but rather as related activities in the single process of growing a timber crop.

ARTIFICIAL FORESTATION

Forests may be renewed by artificial forestation or by natural processes influenced and controlled by the silvicultural system under which the mature timber crop is cut. Although in most cases more expensive than natural processes, artificial forestation has other distinct advantages. It can be used to reduce within a reasonable period the enormous extent of our waste forest lands which are not reproducing naturally. It is the only feasible method for the afforestation of lands such as the prairies which do not bear any timber. It can be used where other methods fail, including the prompt filling in of the inevitable fail spots in natural regeneration. It gives the greatest possible control over the composition of the future forest. This control may be absolute in the case of bare land. It can be used gradually to improve the composition of forests from which the desired species have been eliminated in part or altogether. Taking all of these possibilities together, the area of land which we shall soon have to plant each year will be very large. Artificial forestation is therefore one of our most important forestry problems.

For artificial forestation, research supplementing that already outlined must sooner or later cover all the American species that will be used and all the conditions that will be encountered in planting. This will mean the entire field from seed production and collection and the growing and field planting of nursery stock to the observation of plantations for a number of years or in many cases until they reach maturity.

Seed

Seed investigations should among other things include production, estimating, collection, extraction, storage, treatment and testing. The actual amount of the seed crop over large forest areas has in actual practice been found exceedingly difficult to estimate and research methods have been necessary to develop a reliable technique. Investigations of this kind have been conducted by the Forest Service for several of the most important western conifers, and by Cornell University for some of the northeastern species. Seed extraction by natural processes in such species as the lodgepole pine may involve excessive time or be impossible on account of adverse weather conditions, while the use of artificial heat to open cones will immediately raise important questions of the maximum which the seed can endure without injury. A number of agencies have worked more or less extensively on this problem for different species, the Forest Service chiefly on lodgepole pine, where it was found that humidity was an important factor along with heat. Many tree species such as most pines, with the valuable Norway pine the most striking example, bear large crops of seed only at intervals of several years, and

storage conditions which will retain the maximum or even reasonable viability become highly important. Reasonably satisfactory storage methods for the species now extensively planted have resulted from the work of many forest organizations. Viability and in fact the whole question of germination have been or are being investigated by a number of organizations. The University of Nebraska, for example, has made detailed studies of the germination under various conditions of the seed of 32 species. Among other things, the production of high-grade nursery stock depends in no small measure upon the spacing of the seedlings in the nursery bed, so that advance knowledge of viability must be secured through reliable tests, and it has proven rather difficult to perfect such tests. These examples illustrate the kind of problems which must be worked out completely.

Nursery Practice

Nursery practice offers another set of problems. This includes the most suitable nursery soils, fertilization, watering, cultivation, and other forms of treatment; such questions as the proper amounts of seed to sow in order to get the most favorable spacing of seedlings in the beds, the depth of sowing to get the best germination, season of sowing, degree of shading to develop the most vigorous plants, root pruning, winter protection, cultivation, special methods of weed eradication, age, methods, etc., of transplanting; and finally, in the case of some species, methods of storing and shipping nursery stock. Nursery practice has its soils problems more nearly comparable with agriculture than in any other phase of forestry. It has its own peculiar set of juvenile fungus diseases, and still other protection problems growing out of insect attacks.

Some of the nursery practice now in use has resulted from trial and error through many years, but more or less intensive investigations by nearly all forest organizations which have attempted artificial forestation have been of great assistance by working out such things as the following. Delayed germination for one or more seasons of sugar pine and western white pine seed in Forest Service nurseries once caused much trouble. Slowness of germination resulted in 1, 2, and 3 year old seedlings in the same beds, and greatly complicated the handling of the stock. It was found by suitable investigations that this delayed germination could be avoided by sowing the seed the first fall as early as possible after collection. The slow initial growth of Engelmann spruce formerly required from four to five years to produce seedlings large enough for field planting, and this raised costs to an almost prohibitive figure. It has been possible through improved methods of fertilization developed by the research of the Forest Service to reduce this period to three years, which makes artificial forestation with this species feasible at least on the National Forests. Work of the Vermont Agricultural Experiment Station has demonstrated the value of shaded seed beds for eastern white pine, and that of the Forest Service for many western species. The proper depth at which to sow seed of many of the western trees as well as some of the eastern conifers has been determined. Zinc sulphate has been found by the Forest Service to be very effective in weed eradication in nurseries, when used in proper proportions, and not injurious to coniferous seedlings.

Since practice for no two species can be the same and it may have to vary widely under different conditions for a single species, the volume of work required even for important American species alone is very great.

Field Planting

Field planting involves still another distinct and exceedingly varied set of problems. Only an extensive series of investigations undertaken independently for all the species to be used can determine, for the different field conditions which must be met, such questions as the best season or seasons and technique for field planting; whether seedlings or some form of transplants are best; the advisability or the necessity of taking advantage of shade; the spacing of the planted seedlings in the field; the effect of competing species of the subordinate vegetation, which may in itself make the difference between success or failure; the soil and site conditions which will insure success or cause failure; protection from rodents and insects during the early years of the plantation. Observations of field plantations must be continued on a gradually reducing scale of intensity through a long series of years. The results of improper selection of species or stock, or of planting on unsuitable soils, or of improper spacing may not be evident for several decades, as experience in Europe has shown repeatedly and that in the United States is beginning to show; hence the greater necessity for research in order to avoid excessive expenditures.

Many plantations so far made have been kept under more or less close observation and a relatively small percentage have been intensively checked. Beyond this most forest organizations doing artificial forestation have undertaken intensive planting tests. The results have already greatly improved field planting technique.

Other Problems

Beyond all these problems there are questions which are sometimes very intangible of when and where artificial forestation is advantageous and necessary, questions which involve a knowledge of all the factors and conditions on individual areas and a close consideration of forest and business policy. Questions of this sort arise sharply in connection with practically every large-scale planting operation.

Then there are questions of standards which all things considered should be maintained to insure satisfactory results without excessive expenditures. For example, what standards in the character of nursery stock of different species are necessary and what should they be? What percentage of survival in field planting should be expected?

Special problems in forestation arise out of attempts to plant non-forested lands such as sand dunes and eroded areas, and in most cases distinctive technique is required. To this several organizations in the United States have already contributed. Special problems arise also out of attempts to extend the range of native species or to introduce exotics, on which more or less work has been done by most States, by a good many forest schools and other institutions, and by the Forest Service. Investigative methods afford the only practical means of working out practical requirements and methods in advance of large-scale operations which

might otherwise result in partial or entire failure over long periods of time and in excessive costs and delays.

Results

Early failures over a considerable period of years in attempts at artificial forestation in the United States, particularly those under adverse conditions, were the direct result of attempting large-scale operations in advance of research, and present improvement is due in no small degree to the adoption in practical work of methods developed through investigations. Research to date by many States, universities, agricultural experiment stations, and the Forest Service has furnished a fairly satisfactory foundation for practical operations with eight native conifers, white, Norway, western yellow, western white, and lodgepole pines; Douglas fir, and white and red spruce. On the hardwoods, with the exception of a very limited number of species, such as red oak, most work has been directed to the seven or eight species which are most suitable for prairie, woodlot and windbreak planting. In brief, research, except that of a rather fragmentary and inconclusive character and that which is still in initial stages, has confined itself to approximately 15 species most commonly used in the United States today in commercial operations. There is still much to be learned for the thoroughly effective use even of these species, and any extension of practice to additional species such as is almost inevitable in the future will broaden the requirements for research correspondingly.

NATURAL FORESTATION

Where they are feasible, natural processes of forestation have in nearly all cases the practically conclusive advantage of cheapness. In forest renewal, European experience tends also to prove their general superiority over artificial forestation in such ways as the maintenance of forest soil productivity. This gives commanding importance in silviculture to natural processes of regeneration and to research into their scientific foundation. Natural reproduction may be obtained either from seed or the sprouting of older trees.

Reproduction from Seed

Methods of cutting timber which have the dual purpose of harvesting the mature crop and of the natural regeneration of the forest are known to the forester as silvicultural systems. Investigations of these systems must determine the best for all forest types and for many of the variations of at least the important forest types. The selection, shelterwood, clear cutting with seed trees, and other systems are not rigid and inflexible. They merge or overlap and are subject to wide adaptation to meet varying conditions and requirements. The problem is almost as much to work out necessary modifications and adaptations as to determine the systems themselves. In short, we cannot either satisfactorily adopt or adapt European or other silviculture without further knowledge, but instead our investigations must develop around our own species and forest conditions the methods which will meet our needs for timber.

Many of our forest stands are ragged from fire and disease and unregulated cutting and will require special transition treatment over a long period of years before the ideal silviculture is feasible. This may be true of some of our eastern hardwood stands where the best species and the best trees have been culled in a series of operations which have left

the poor trees and species and the forest has been further deteriorated by repeated fires. Special transition treatment may also be required in the conversion of virgin stands to second-growth forests. Undoubtedly a different silviculture will, for example, be necessary for cutting the second-growth Douglas fir stands on the Pacific Coast from that which is now being developed for mature and overmature forests. Research must determine the best transitional measures which will be most effective if they can have clearly in view what the final silvicultural methods will be.

Wide differences will be found even within the same forest type which will require variations in silvicultural treatment. The Douglas fir type of the Rocky Mountains is so absolutely different that it will undoubtedly require other methods of cutting than those which are suitable for either the virgin or second-growth stands of the Pacific Coast.

Since one of the chief objects of silvicultural systems is the perpetuation of the forest, all problems of forest regeneration become correspondingly important. Under some conditions this will involve the determination for different species of what constitutes a good seed tree. How large should it be? Investigators in the Forest Service have found, for example, that in the Southwest the larger and more mature western yellow pine trees may be depended on to produce five or six times as much seed as the younger and smaller "blackjacks" of the same species. How many are needed? Is the character of the crown a factor? What are the distinguishing characteristics of the best seed bearers? In which trees can seed production be best combined with maximum growth? With maximum immunity from forest fungi, or from insect attacks? To what extent must danger from windfall influence the selection of seed trees? In mixed stands how must widely different seed-producing capacity, methods of dissemination, germinating habits, etc., be taken into account in the selection of seed trees in order to retain desirable mixtures? To what extent and how must difference in soil and climatic conditions and topography be taken into account?

Seed dissemination, which varies in extreme from the heavy-fruited trees such as the oaks to those with winged seeds such as ashes, maples, and most conifers, is of obvious importance. So also are the germinating habits and requirements. The germination of some kinds of seed is aided by the forest litter but others require mineral soils. The acorns of some southern Appalachian oaks commonly germinate in the fall and the seedlings may be killed during the winter, while others may gain a distinct advantage in competition by holding over until spring. Yale University is studying the whole question intensively in cooperation with the Forest Service. Forest Service investigations have shown that in the Douglas fir forests of the Pacific Northwest and also in the western white pine forests of northern Idaho it may often be possible in forest renewal to take advantage of seed in the duff which holds its vitality over a period of several years. In both regions, such advance reproduction as exists is of hemlock and other species of the climax forest, most of which will not ordinarily be desired in large proportion in the final stand, so that an entirely new reproduction in which the fir and white pine will predominate will be a great advantage.

The key to the perpetuation of the western yellow pine type, as shown also by the work of the Forest Service, will undoubtedly be through ob-

taining advance reproduction by protection from fire and overgrazing and by saving this advance reproduction in logging. In such types as the mixed spruce and hardwoods of the Northeast the coniferous seedlings are able to endure heavy shade over a long period of years and to grow rapidly when released. Here again it has been found that in order to insure a reasonable proportion of the conifers in mixed stands it is necessary to protect advance reproduction in logging, because it has been found exceedingly difficult to obtain satisfactory reproduction after cutting. These are merely examples, however, of a very large number of questions which must be answered for all of the types and species which it is desired to perpetuate, and even for those species which it is desired to exclude from our forests.

The ability of trees which are left in cutting to respond by increased growth is an important factor in silvicultural systems. Investigations by various forest organizations show that most trees of the species studied respond to release after cutting only when their crowns are able to function effectively. This means a heavy crown capable of further development or, as a minimum, a delay in increased growth until a good crown has been developed. Questions of light are involved as well as tolerance and other physiological characteristics of the trees themselves. The physiological reaction and hence the silvicultural technique necessary to obtain an increased rate of growth will vary for different species and for the same species in youth, middle age, and maturity.

All silvicultural methods and their adaptations must be based upon a knowledge of the influence upon individual types and species, of such factors of environment as soil, climate, subordinate vegetation, and topography, knowledge which can be obtained in an authoritative way only through research. They will also be influenced by such additional factors as logging utilization and protection which will be taken up later.

Reproduction from Sprouts

Forest renewal by the sprouting from stumps may be employed in our hardwood types and will probably prove the means of obtaining a substantial part of new stands in the California coast redwood forests. The sprouting of seedlings and saplings which have been killed is probably an important factor in keeping in the southern pine forests a tree so sensitive to fire in its youth as shortleaf pine. The investigation of ways and means of obtaining the best sprout forests or of obtaining a combination of sprout and seedling forests must be of somewhat the same general scope as those for natural reproduction from seed. Many distinctive questions will arise, however, such as the best season and manner of cutting to insure good sprouting and the effect of fire, age, soil, and climate on the sprouting capacity of stumps. Already special adaptations to American conditions have begun to appear. The cutting back of advance oak and ash seedlings in the mixed forests of central New England, as developed by Harvard University, gives rise to sprouts of much more rapid growth and to trees of much better form and hence quality than the seedlings themselves.

CULTURAL OPERATIONS

A series of cuttings of various kinds may be required during the process of carrying forests through to maturity, regardless of their origin.

These cuttings may take the form of thinnings or improvement cuttings. The same general objectives hold in both, increased production of timber, or timber of a desired quality, increased health and vigor of the remaining stand, the prevention or elimination of disease, the salvage of dying trees, and earlier financial returns.

Thinnings may be made to yield desirable small-sized products such as posts, props, poles, and pulpwood. Here again we shall not be able to apply European systems adapted to different species and conditions, but instead shall have to develop new or modified systems. The western yellow pine stands afford an illustration in which small even-aged groups of trees make up what as a whole is essentially an uneven-aged stand. This necessitates a new method of thinning for which we have no European counterpart. What this method should be must be worked out by research. Many forest agencies in the United States have under way some work on thinnings and this will have to be increased gradually as thinning operations become commercially feasible.

The transition already referred to from the ragged, uneven stands which are now so extensive in our forests may often require improvement cuttings in the initial stages of bringing such stands under forest management. Research must pave the way for thoroughly effective operations adapted in each case to conditions and requirements and leading as rapidly as possible toward an ideal silviculture.

Another form of cultural operation common in European practice and frequently appearing in programs of European forest experiment stations is the pruning of forest trees. American conditions now rarely justify such methods. Sooner or later, however, we shall follow European precedents and institute pruning experiments on those high grade American species such as white pine, or black walnut, in which the maximum amount of high grade lumber is desired under the shortest possible rotations.

SLASH DISPOSAL

The disposal of slash and débris from logging operations is an essential part of silvicultural methods. Frequently the method of disposal employed has an important bearing upon the success or failure of reproduction. After cutting in virgin stands of coast Douglas fir, slashings must ordinarily be broadcast burned in order to remove the immense quantity of highly inflammable material and thus reduce the fire menace. Studies so far made by the Forest Service indicate that they should be burned as soon after the cutting of the timber as possible with safety; otherwise the seed stored in the duff has an opportunity to germinate, and fire by killing the seedlings removes a very favorable opportunity for a new stand and may necessitate artificial planting. Work in the Forest Service has also shown that seedlings of the southern white cedar need light for development, and where logging has left the ground covered with slash, few seedlings can make their way through it. Slash burning so controlled that it will destroy the material left after logging but leave the duff in which the seed is stored may be necessary to insure reproduction. Broadcast burning of slashings in western yellow pine stands, on the other hand, has been shown by the Forest Service to kill advance reproduction and delay the starting of a new crop for many years, or in aggravated cases indefinitely.

Unless removed slash constitutes the chief fire hazard in most forest types for several years after cutting. In some regions at least, fires originate largely in slashings from which they escape into stands of green timber. Slash may in some cases increase insect infestation and forest tree diseases. It becomes less and less of a menace as utilization becomes more complete.

Questions such as the following must be answered: How much of a fire menace is slash? How long will the menace last? To what extent, if any, does it aid or interfere with forest reproduction? Does it increase the threat of fungus diseases or forest insects, and to what extent? What effect, if any, does it have on the subordinate cover? On soil conditions? How best can the slash menace be removed—by piling and burning, by lopping and scattering, by special patrol during the period of especial hazard, or by other means? All of these relationships—reproduction, fire, utilization, insects, and fungi as well as additional relationships to subordinate vegetative cover, soil conditions, etc., must be worked out for all forest types and regions in the entire United States and given definite expression in effective methods of slash disposal. The Forest Service, independently or in cooperation with the Bureaus of Plant Industry and Entomology, has investigations of slash disposal under way in eight of our forest regions and additional work is being done by other agencies.

SILVICULTURE AS INFLUENCED BY OTHER FACTORS

Logging

Cheap exploitation has hitherto been practically the sole objective in the development of American logging methods. The perpetuation of the forest through the leaving of second growth or seed trees has rarely or never been a factor. Logging in large virgin timber, particularly on the Pacific Coast, has come to rely on power machinery. Both high lead, in which the logs are lifted clear from the ground for at least a part of the time, and the use of high-speed donkey engines, which drag logs as fast as 1,000 feet a minute, are very destructive of the smaller and younger trees which should be left in such types as the sugar pine–western yellow pine as a nucleus for a new stand. Investigations by the Forest Service have shown high-lead logging in this pine type to be so destructive that it should be ruled out where young stands are to be preserved, unless it can be greatly modified. The operation of moderate speed donkeys may be so modified as to permit their use. These, however, are merely examples of situations which require investigation in order that logging methods may take into account forest management as well as exploitation.

A somewhat different class of problems involve logging and both silviculture and utilization. Investigations in the Lake States, California, the Northern Rocky Mountains and the South by the University of California, the Forest Service, and a number of other agencies show, for example, that the smaller-sized trees in the uneven-aged stands of many types can be logged only at a loss considering costs of handling and the low-grade product obtained. In these cases the leaving of the younger part of the stand for a new crop, or good silviculture, coincides with the best logging practice. It has in every instance, however, required investigations to bring out the fact, and further investigations are necessary in the regions mentioned and many others to show exactly where the line should be

drawn under specific sets of conditions between silviculture and utilization. In short, what we badly need in the United States is a new logging engineering with a silvicultural background.

Utilization of Timber and Other Products

Frequently the product that the owner desires to raise will dominate the silvicultural system. For example, the growing of hemlock for pulpwood and of Douglas fir for saw timber in the Pacific Northwest will probably require radically different silvicultural treatments. In stands of longleaf or slash pine in the South the owner may desire to obtain both naval stores and timber. Naval stores production, in which the chipping of the tree is the first step in utilization, introduces a series of new problems extending far beyond the physiology and morphology of resin production into silvicultural methods roughly analogous to methods of cutting. The determination of a balance between naval stores yields and the character and volume of lumber or other timber yields inevitably influences the silviculture.

The status quo in utilization need never be accepted unless under it good silviculture is possible. The status quo need never be accepted in any case, because better utilization will always make possible more intensive and better silviculture. It may be perfectly feasible through suitable investigations to develop markets for species commonly regarded as inferior and thus permit silvicultural treatment which will insure the proper proportion between species in the future stand. Better utilization may be made to remove a large part of the material which would otherwise be left on the ground and constitute a fire menace. It may equally be possible to increase the opportunity for thinnings and the cultural operations which take out the poor and defective trees.

Utilization will depend to a considerable extent upon the quality and the properties of the product produced by silviculture. Foresters for many years have killed off the lower limbs of trees by shading to obtain a clear, high-grade product. Silvicultural technique offers about the only means for the control or modification of the factors of environment which influence the properties of the wood and so make it possible to produce products with special properties where this is desired. If the falling off in the growth rate must be prevented in order to obtain particularly tough wood as the research of the Forest Service has shown to be the case in ash and hickory, the opportunity is offered through thinnings. This is merely an example of the methods that we shall have to employ in the future to obtain products with special properties. It is becoming more and more clear that the most profitable forestry of the future will be that which produces high-grade or special products for which special prices may be obtained, because the markets are rarely or never oversupplied.

With research for the improvement of silviculture must therefore be coordinated research described elsewhere in detail for the improvement of utilization or designed to improve the properties or quality of the product. Silvicultural research must have as an objective the growing of the desired products and utilization research must have a corresponding objective of making good silviculture profitable.

The forest may render its service partly in the form of forest influences in addition to wood and other forest products. The need for this

service, which is considered in detail elsewhere, may under some conditions dominate the form of silviculture; how and to what extent can best in most cases be determined by research. Most important among such influences will be the regulation of streamflow and the prevention of erosion. Protection against avalanches will be much more rare.

In some cases it will be desirable to combine production of timber and the production of forage for livestock grazing. If the production of timber is the dominant use, as it will be in practically all cases, necessary adaptations in technique may be confined largely to range management. An intensive investigation of possible dual use of southern pine lands for timber growing and livestock grazing is now under way in the South through the cooperative efforts of the Forest Service and the Bureau of Animal Industry and the State of Mississippi.

Protection

More and more in our silvicultural practice we shall have to take into account not only forest renewal and growth but forest protection against fire, fungus diseases, and forest insects. The basis depends upon research. It may be found, for example, that the relatively lower fire hazard of the green forest may tip the scale in favor of partial as contrasted with clear cutting in some forest types. This may be true in the birch-beech-maple forests of the Lake States. Some of the most effective methods of protection against fungi and insects, since they will be preventive, may also be through silviculture technique. Methods may be adopted which will insure mixed stands or stands of mixed conifers and hardwoods, because the menace of insect or fungus attack is thereby reduced. The danger of attack in other cases may be minimized by keeping to a minimum, or at least below a prescribed maximum in the stand, species particularly susceptible to attack, like the balsam fir to the spruce budworm. These possibilities of protection and their scientific basis will, however, be considered in more detail in a subsequent section.

Special adaptations of silviculture required for protection against climatic phenomena must also be worked out. Cuttings in shallow rooted species, such as the spruces and firs, have indicated that the danger of windfall losses in the reserved stand must be taken into consideration. In northern Idaho the amount and the damage done by sunscald to the reserved western white pine is a factor in the degree of cutting which should be permitted. Questions such as the following must be answered. What mixtures of species or other silvicultural measures will reduce to a minimum the damage from snow, sleet, frost heaving of seedlings? How and to what extent must partial cuttings take into account the danger from windfall? How far can forests be opened without danger from sunscald?

SILVICULTURAL CRITERIA

The results of the investigations outlined will be expressed in the technique of silvicultural systems, thinnings, slash disposal, etc. But within such methods we should in many cases set up criteria to serve as concrete guides to practice and hence to the best results. In the open western yellow pine forests of the Southwest, for example, satisfactory reproduction may mean 1,000 seedlings to the acre at an age of 10 years,

whereas in the Douglas fir forests of the West coast we might not count as satisfactory any less than 2,000 seedlings at 5 years. Similarly we should know sooner or later about how many trees our stands should contain at subsequent periods of their development in order to insure maximum growth or the most desirable properties. For mixed stands we should know the desirable number of each species at the seedling and subsequent stages. In the determination of such criteria practically nothing has as yet been done.

PROGRESS AND OUTSTANDING PROBLEMS

The results of research in artificial forestation have already been discussed. From other phases of silvicultural research we have to date acquired special knowledge, chiefly on methods of cutting and brush disposal, for a passable silviculture in half a dozen of our most important forest types. This information, to be sure, still has many serious gaps but is sufficient for a reasonably satisfactory practice. On half a dozen more types there is a much smaller and less satisfactory special knowledge. For all the rest of our numerous types we have the most fragmentary information only. In these until something better is available practical silviculture must have its foundation in European analogies and our own knowledge of and experience with other trees and types. Even on this basis partial timber crops can be grown and forest lands kept fairly productive.

The solution of the silvicultural methods problem involves in part the use of an extended series of permanent experimental plots or areas in all of the forest regions and types of the United States. Many agencies together, State forestry departments, forest schools, private owners, and the Forest Service, have already laid out several hundred methods-of-cutting, thinning, and other sample plots in possibly twenty of our forest types. Some of the oldest go back twenty years or more. Most have been established within the last decade. This represents, however, only a small beginning in the number of sample plots which we shall have to have. No one type in the United States as yet has anything approaching the number required and many types have none. Furthermore, such plots will have to be kept under observation for decades. We shall probably never get away from the need for large numbers as long as any attempt is made to grow timber in the United States. Extensive use of such sample plots in European research has aided in showing such things as the rather striking advantages of natural processes of regeneration as opposed to clear cutting and planting of pure stands in Germany because of gradual soil deterioration and the falling off in productivity. The sample plot method, however, is only one of the many which must be used in obtaining the investigative basis for good silviculture.

The silviculture of final cuttings, thinnings, improvement cuttings, slash disposal, etc., constitutes one of the most important groups of problems which the forester has to face. In silvicultural technique the forester has the most effective instruments for forest renewal, vigorous growth, desired quality and even properties of the product, and to a certain extent also those for protection from fire, insects, and disease. In this technique under present conditions, the determination of silvicultural systems and required adaptations and slash disposal are most urgent, along with the

improved logging methods and utilization which in many cases are a prerequisite to putting the most desirable silviculture into effect.

3. FOREST MENSURATION

An inventory of the forest crop is a first essential to rational forest management, and for this, "volume tables" are needed. These state for given species and conditions of growth the average volume which may be expected for trees of given dimensions. A reasonably exact estimate of the future productivity of a forest property is also an obvious prerequisite to any intelligent plan. The tool for predicting timber growth is the "yield table," which states the major characteristics which are to be expected in stands of given ages growing under given conditions. While the forestry profession has been urging timberland owners to apply forestry to their holdings it has not, except in isolated instances, provided adequate yield tables, and the volume tables extant, while more numerous, are far from satisfactory.

The major problems, therefore, of this branch of forest research are:

1. The preparation of volume and yield tables for American species and types.
2. The standardization of the form and substance of these tables and of the technique of their preparation and application.
3. The investigation of the fundamental laws of tree form and tree growth.

Present Status of Volume and Yield Tables

For practical reasons the dimensions of a tree which are measured when its volume is to be estimated are the diameter breast high, or 4½ feet above the ground, and the total or merchantable height. It is known that the volume of trees of given dimensions varies with the species, age, and conditions of growth. Since there are about 180 species in the United States of considerable commercial importance and since several tables are obviously needed for each, the task of preparing a complete set for the entire country is large. Furthermore, several thousand tree measurements have been considered necessary for an accurate table.

Large numbers of tables, for virgin timber of some 75 species, and for second growth of about 20 species, have already been prepared by a large number of different agencies, but in such diverse ways that it is often next to impossible to tell which tables are applicable to a specific problem, just how they should be used, or how accurate results may be expected.

A striking example is in the case of volume tables for western yellow pine, of which 80 or more are now extant. This excessive number reflects differences in technique rather than in tree form, and it is highly probable that a half dozen or more tables could be substituted with a gain both in accuracy and ease of application. A study of this specific problem by the Forest Service has advanced to a point where this result can be clearly foreseen.

Yield tables have been prepared by many different agencies for well up towards 50 species in pure, even-aged stands, and for perhaps half a dozen of the great number of forest types in the United States. Many of these tables are either doubtful in accuracy or difficult in application. The

varied standards adopted have introduced serious difficulties into their use by any but their authors. Some common agreement on disputed points must be reached before real progress is possible, and a satisfactory decision often depends on an understanding of some unknown law of tree or stand development.

Standardization of Volume and Yield Tables

It is clear, then, that progress in supplying the needed series of volume and yield tables depends on an adequate standarization of form and methods, and will be facilitated by fundamental investigations of underlying principles. The series of tables is the main objective, but it will be produced more rapidly and economically if the actual preparation of tables be, for the present, somewhat subordinated to the solution of the second and third problems mentioned.

Considerable progress toward uniformity of treatment has already been made by a special committee, representing different interests in the American forestry profession, including the Society of American Foresters, the Association of State Foresters, and the Forest Service.

The adoption of standardized methods should be followed by a thorough review of the existing tables, and probably in many cases by their revision. This and the huge task of preparing tables for all important species and types can then go ahead with an assurance that the results will be comparable, and relatively easy to use. In cooperation with the National Research Council, the Southern Pine Manufacturers' Association and several States the Forest Service has recently completed volume and yield tables for the principal southern pines under the plans formulated by the committee, and the Forest Service has under preparation similar tables for such species as Douglas fir, yellow poplar, southern white cedar, red spruce, jack pine, and others.

The Fundamental Laws of Form and Growth

It is fortunate, perhaps, that this standardization has not previously been accomplished, for technique is now undergoing radical changes through the use of the modern science of statistics. Its conceptions have only recently been introduced into forest research and the possibilities of its rigorous mathematical processes are as yet but partly understood. Here is a field of effort of the greatest promise, for from it both increased accuracy and economy of effort may confidently be expected. For example, it seems clear that instead of several thousand trees for a volume table, a new technique should permit improved results on perhaps a tenth of this number.

Early forest research relied largely on graphic methods in which the personality of the investigator played too dominant a rôle. The same basic data might readily lead to radically different conclusions in the hands of two equally experienced workers. The statistical method, with its purely mathematical processes, goes to the other extreme and arrives at results with mechanical exactitude. On the other hand, it often pronounces its own findings to be unreliable unless based on an enormous number of data. There appear to be unusual possibilities of a new technique which combines the advantages of both these methods and applies the rigorous analysis of statistics to the graphic methods which utilize to the utmost the

knowledge, judgment, and experience of the worker. Current research in the Forest Service is in fact working this out, and has indicated, for example, in the case of Douglas fir that a volume table can be prepared by an analysis of multiple curvilinear correlation between form factor and height and diameter. This method has even wider use in permitting a ready evaluation of other factors such as site and age.

The graphic method is practically limited to cases where the effects of one or two variables are being studied. Most forest problems involve several, and the new statistical technique can handle these in a far superior manner. Its introduction into forest mensuration is perhaps as important on this account as because of its increased accuracy and reliability. Obviously, it facilitates a search for the fundamental laws of tree form and growth.

The investigation of the volume of second-growth trees should for one thing determine the fundamental laws of tree form, and what factors modify them and in what manner. It is known, for example, that factors such as growing space and accelerated growth following cutting cause variation in form. Form may even be different on the same site in different regions. Swamp grown red gum has a different form from that on well drained soils. When these laws and the causes underlying variation have been determined, their application to individual species should follow. This latter phase, while exceedingly laborious because of the large number of our species, should be comparatively simple. Two empirical equations of form based on different theories of taper have already been developed that are most promising, although as yet but little or no attempt has been made to relate them to the conditions of growth which are the fundamental causes of variation.

One of these, developed recently in the Forest Service, is based on an equation of hyperbolic form. It has been applied with some success to a number of the northeastern species and appears to be capable of possible further extension. This method appears to be much more simple, more accurate, and capable of wider use than the Swedish exponential equation. Both need a large amount of additional study before either can be accepted as final or widely used in practical work. It is doubtful if either will apply to hardwoods. Little progress, moreover, has yet been made in determining what factors control the constants of the equation.

These mathematical formulae are apparently not readily applicable to virgin timber for which a more superficial treatment is indicated. Virgin timber is on the average very old, far older than it will be practicable to raise under forest management. Its form is moreover quite different from that of younger trees, so that distinct volume tables are needed. The tables for very old trees are, in a sense, of relatively transient importance, and of value merely for the period during which the remaining virgin timber is being cut. During this period, however, which will last for a number of decades in the far West, they are of considerably greater importance than those for second growth. In several parts of the East, they will also be needed for some years. While the preparation of such tables cannot wait for the development of an adequate equation of form, the possibility of improved accuracy through separate tables for different site classes should, in particular, receive attention. For the present, this can probably be best accomplished by graphic methods, which work of the Forest Service and the University of California on the western yellow

pine and white fir has indicated to be fairly adequate for this purpose. The improved statistical technique also promises to contribute materially to a better understanding and solution of this problem.

Practically nothing has yet been accomplished towards finding a mathematical equation for growth, or determining the effect thereon of the controlling factors. Normal spacing for different stands is exceedingly puzzling. We do not know for different species what variations overstocking or understocking in youth, or cultural operations, will bring about in rate of growth or in form and volume of individual trees and hence the stand, nor how they will finally affect yields. Recent investigations, however, are laying a foundation for this much-needed work. The traditional use of three or five arbitrary "site classes" is, for example, being abandoned in favor of the more flexible quantitative expression "site index." Recent yield studies, moreover, have successfully worked out in a preliminary way the laws of the distribution of diameters about their mean in the case of pure, even-aged stands of certain species.

Other Problems

Aside from the actual preparation of volume tables for all of our species and of yield tables for all of our types, the most important problems in forest mensuration are the development of satisfactory methods of yield determination for uneven-aged stands, and of methods for applying yield tables of all kinds to our partly-stocked stands. Uneven-aged stands of both pure and mixed species constitute one of our most difficult problems in growth and yields. The greater part of our present forests are uneven-aged. It is probable that the selection system of cutting will be found most suitable in many of our forest types for many years to come if not indefinitely. Here we may have to fall back upon growth tables for individual trees with supplemental information on mortality or losses which will permit the application of the data to stands.

Stands of mixed species, and particularly those which are uneven-aged, such as the hardwoods of the eastern United States, present peculiar difficulties, which remain to be worked out since but little effort has yet been made along this line. This will be a large undertaking.

The practical application of yield tables involves a number of elements as yet only partly understood. Factors for the reduction of values from tables based on fully stocked stands to make them applicable to the ragged, partly stocked stands which are the rule rather than the exception in our American forests, are to-day little more than intelligent guesses. Investigations leading to more accurate solution of this problem involve long-time studies and repeated measurements of a large number of stands covering a variety of conditions and should invariably therefore go hand in hand with the preparation of yield tables.

FOREST PROTECTION

The various kinds of forest protection are in the last analysis very specialized phases of forest management, and for this reason as well as for clearness and emphasis they are discussed separately. Of the three major agencies of destruction to the forest, fire, fungus diseases, and forest insects, fire is the most spectacular and attracts most attention,

although it may not do as much damage in the aggregate as either of the other two. A fourth and miscellaneous group of destructive agents, on the whole of much less menace, includes among other things destructive storms and various animals. For these destructive agencies there is the common necessity of developing by research special adaptations of forest management to take their place among the most effective preventive measures. Of the entire group we have fewest and least valuable precedents from European and other foreign practice in fire protection, and this is particularly true in research.

1. FOREST FIRES

A statement of what foresters and land owners must be able to do in protection against fire in order to grow timber is a prerequisite in outlining the needs which fire research should meet. They must know concretely what dangerous fire conditions are and must have available methods of predicting them. They must know how to prevent forest fires just as far as possible, and to suppress with the utmost efficiency those which do start. They must have standards of protection, based directly upon the silvicultural objectives of the type and region and owner. These standards must be made attainable at lowest costs by the proper distribution and handling of the protective force. Possibly they should also be able to set limits beyond which expenditures for protection are not justified, that is, the determination of the point where the law of diminishing returns becomes effective. But if used at all these limits should be set upon very comprehensive rather than narrow considerations.

Laws of Combustion

One of the most important problems which require solution in forest fire research is the determination of the laws governing the combustion of forest fuels in the open. These fuels include an almost infinite number of materials. In a single locality their volume or character may change slowly from year to year or rapidly from season to season. In different localities even within short distances they vary within the widest limits in bulk, volume, and character. They vary between forest trees and undergrowth, between living and dead material, between the mature and the young forest, between dense and open forests, between clean forests and cut-over areas cumbered with débris, between different species of trees, tree mosses, and subordinate plant life. All of these variations in the character, amount, and distribution of fuels influence combustion.

Numerous and variable though they are, the fuels themselves constitute only one set of factors in the laws of forest combustion. The same fuels may at different times vary from ignition with great difficulty to the highest inflammability, depending upon whether they are live or dead, wet or dry, or in short upon their moisture content. Depending among other things upon moisture content, the part of the fuel which actually burns in any one fire varies greatly. The moisture content is one of the chief factors determining the fire season, its beginning, peak, and end.

Moisture content, however, merely serves to link fuels on the one hand with seasonal and atmospheric conditions on the other. Some of the more obvious atmospheric factors which influence combustion are precipi-

tation, wind, and temperature. Recent investigations of the Forest Service have shown relative humidity also to be peculiarly important, under many conditions at least. Thoroughgoing research may add a number of other factors the existence and importance of which we now only vaguely suspect, such as the electrical conductivity of the atmosphere, if investigations of dust explosions in threshing machines and mines can be taken as an indication. There is reason to believe that there is a relationship between sun spots, electrical discharges from the earth, static conditions in the atmosphere, and electrical storms; and possibly even other climatic phenomena which may have a bearing on combustion. Pronounced differences in combustion have even been ascribed to the differences in atmospheric condition resulting from altitude.

These atmospheric factors vary as widely as the fuels and most of them change much more rapidly, although investigations of the Forest Service in several regions show that forest litter and dead vegetation follow with surprising rapidity the fluctuations of the relative humidity of the air. When understood, the atmospheric factors will furnish the key to the apparently larger regional differences in climate not yet clearly defined, which definitely affect the broader aspects of the fire problem. As an example, the opinion has gained credence that there is something in the atmospheric conditions of the central Rocky Mountain region which makes it relatively easy to prevent serious conflagrations even in the driest years. That such conditions are not always in control, however, may be shown by the extensive areas which have been burned over in the past, during and for centuries prior to the early years of white settlement. The inherent danger lying in such an empirical conception is the strongest possible argument for a thoroughly scientific understanding of the facts.

Unfortunately, the factors contributing to combustion do not end with fuels and atmospheric conditions but include also topography, where, other things being equal, variations of slope, aspect, and the comparative height of the hills make all the difference between fires which can be extinguished without difficulty and those which practically no human measures can control.

The actual behavior of forest fires or the process of combustion represents, therefore, a complex made up of a large and exceedingly variable number of factors which act and react upon each other in innumerable ways. Full knowledge will bring with it an understanding of the ease or difficulty of ignition of various fuels from various causes, such as matches, cigarettes, locomotive sparks and lightning. It will bring an understanding of the jumping of fires which makes suppression so much more difficult, of the conditions under which a whole mountain side apparently bursts into flame almost simultaneously, of the causes for the transformation of the relatively easily suppressed ground fires to crown fires ordinarily impossible to control. But a thorough understanding of this complex must include still more an exact knowledge of the conditions which a going fire creates for itself—of the purely local drafts and winds, and of the occasional hurricanes, such as that of 1910 in the northern Rockies which swept over thousands of square miles of territory, or that of 1918 in northern Minnesota. In short, full knowledge should give a complete understanding of the ignition character, spread and behavior of fires under all conditions. Only the barest beginning has been

made in intensive studies of the behavior of forest fires and that chiefly by the Forest Service.

Altogether the laws of forest combustion are a subject of vital importance, for upon an understanding of them should rest the whole technique and generalship of fire suppression and many important elements of fire prevention. It will be necessary to go beyond a scientific understanding of these laws and determine the crucial points in order to permit effective application by fire prevention and suppression forces. One means to this end may be a classification of fuels and the other factors which influence the laws of combustion. In any case what constitutes safe, dangerous, and critical conditions must be determined concretely and defined sharply. Simple, practical ways of measuring these conditions reliably must be worked out, so that they can be recognized by the isolated patrolman and the fire fighter. It is probable that separate determination for each forest region will be necessary since work so far done by the Forest Service indicates that what may be a critical factor in one region—relative humidity, for example, in the Pacific Northwest—cannot be used alone with equal advantage in other regions of different forest and climatic conditions. The problem in the broad becomes first, therefore, one of a thorough understanding of the laws of combustion, and second, of picking out and putting into simple, usable form the essential, crucial points needed in fire prevention and suppression.

Fire Prevention

The research required for fire prevention and suppression is partly for the application of that already outlined under laws of combustion, but it includes also additional research of a more or less fundamental character. One effective means of fire prevention is the removal of inflammable material. This, where it is feasible, is a purely administrative activity, but the determination of whether removal is really worth while goes more or less deeply into research. It deals with subjects such as those already discussed, of the necessity for the disposal of slash and débris resulting from cutting, which is ordinarily a protection measure pure and simple, and the reduction of the fire menace by livestock grazing of the forest undergrowth.

Another means of prevention is through the maintenance of forest conditions. Prevention of this sort depends upon moisture retention by dense forests and the higher risks resulting from the drying out of heavily- or clear-cut forests. The precise extent to which forest density is a factor and how far it can be maintained because of other silvicultural considerations must be worked out for various forest types and regions.

Even prevention by the apparently simple provision of efficient spark arresters in locomotives and logging machinery leads quickly into the necessity for an understanding of combustion in boilers, effective design, the throwing of live sparks, and the possibility of forest fires from sparks of various sizes under different conditions. It was this background that led to a study of the throwing of sparks and of their inflammability by Purdue University. Most of the effort on spark arresters has been developmental rather than investigative.

Europe resorts lavishly to the breaking up of forest areas by firebreaks, designed to check the spread of fire and make control easier, but

costly to make and maintain. Their use and practicability under American conditions has generally been questioned but without much basis, except that of cost. Sooner or later, however, they will have to be tested and, best to begin with, on a small scale under close observation.

Another potent means of fire prevention lies in the prediction of dangerous conditions and especially of critical conditions. Investigations of laws of combustion should define these conditions sharply, but if, for example, relative humidity below a specified point is one such dangerous condition, much meteorological research may be required before satisfactory predictions of the dangerous humidities can be made. If the dangerous condition is a characteristic dry wind, much may remain to be worked out in its prediction and in the adaptation of general wind predictions to local regions in rough and mountainous country where striking local variations ordinarily occur. In the West fully 35 per cent of the National Forest fires are caused by lightning, and a thorough understanding of electrical storms, when and how they occur in relation to general storm movement, their course, the interrelation of fire-starting bolts and rain, and similar questions would be invaluable first of all in predictions, but equally or more in catching while small and easy to put out the fires so likely to start in remote mountain areas. Lightning storms are therefore being studied by the Forest Service in most parts of the West where they are serious. Under some circumstances predictions of a few hours may be of the utmost importance, but the farther in advance they are the better because of the opportunity afforded properly to adjust the protective force or to make any other administrative provision which the situation may seem to demand.

Any investigations, therefore, of seasonal variations, climatic cycles, of the relation to critical fire weather of variation in solar radiation from sun spots or other causes which enable long-term predictions, may be translated into more fires prevented, more caught while small, reduced protection and suppression costs, and larger, better and more profitable timber crops. During periods of critical fire weather it may be of equal importance in fire generalship to have predictions of the return of favorable weather conditions. The Forest Service has studied the prediction problem in a number of regions, including the relation of static to fire weather, as has also the Weather Bureau which is now embarking on a comprehensive investigation of the entire subject.

Still another effective means of prevention is through appropriate investigations of the origin of past fires. Man-caused fires bring several entirely distinct groups of problems ranging from the incendiary fire to the immense numbers resulting from carelessness and to those growing out of industrial operations such as railroads, logging, ranching, etc. In the last analysis, many questions of human psychology in relation to the destruction of both private and public property and law enforcement are involved. These problems become more and more acute as logging operations are extended, the country is settled, the movement for outdoor recreation grows and roads and trails are extended into remote districts. This group of problems is one on which the Forest Service has devoted considerable effort and the work is now being taken up by several States.

Prompt and reliable detection of fires from the high mountain peaks used as lookouts brings for solution still other problems, such as visibility

as affected by atmospheric conditions, by angle of vision, by the direction of vision, by topography, and by timber cover. Studies of the appearance and volume of smoke produced by fires in various sorts of cover would greatly improve the vital process of fire detection.

Fire Suppression

Methods of fire suppression are now based largely upon judgment formed from actual experience in fire fighting. Effective suppression methods should be based instead upon the fullest scientific understanding of the laws of combustion of forest materials—supplemented by experience, to be sure. Scientific fire fighting should utilize to the maximum the fundamental laws of nature, and to the minimum man-power and money.

A prime essential is that all the knowledge which can be obtained of fires and their behavior and of effective methods of attack and suppression shall be crystallized into correct and simple principles of generalship and tactics of fire fighting. This should serve as a guide to thoroughly effective administrative action. To this end research must go beyond the field already outlined and study the actual handling of past fires in exactly the same fashion that soldiers study the history of battles in order to develop the tactics and generalship which shall guide military action. Altogether this is an enormous task requiring years of work for fully satisfactory fruition.

But beyond tactics and generalship research can help also in putting weapons into the hands of the fire fighter. One essential part of scientific methods must be instrumentation which will give an authoritative check and guide to judgment in determining on the fire line just what conditions are and how they are changing. This will mean both the development of simple, foolproof instruments and of instructions for their use. This tendency as a direct result of research by the Forest Service is already beginning in the widespread use, particularly in the Northwest, of the sling psychrometer. Suppression equipment has received some consideration from many organizations but is deserving of much more. It has so far resulted in portable gasoline pumps which are very effective under some conditions. If the field were surveyed thoroughly, as it should be, opportunity would unquestionably be found for the improvement of much existing equipment or the development of other forms entirely new.

There is a distinct possibility that transportation of men and supplies to fires in thinly populated regions may ultimately depend on lighter than air machines. The obstacles at present in the way of such transportation are the lack of noninflammable gas such as helium at low cost, the high cost of dirigibles, and the lack of equipment and skill necessary for anchoring dirigibles in the woods and landing men from a balloon when anchored near a fire. These obstacles may not be found to be insurmountable and, when overcome, the use of balloon transportation may easily call for reorganization of the distribution and use of forces with great advantage to the efficiency and economy of fire control.

Fire Damage

Much of the damage caused by forest fires is obscure and not as easily determined as might appear. It is this very obscurity that is largely

responsible in so many regions for the widespread belief that accidental fires, or those set in "light burning," do no damage. The difficulties are so great that only intensive investigation can give any real measure of the extent of fire damage or develop simple, practical methods for its evaluation.

Different species of forest trees differ within wide limits in their susceptibility to fire. The California redwood withstands the most severe fire without apparent injury, while the thin-barked western white pine, apparently uninjured by an innocent-looking creeping ground fire, later succumbs. Other species such as the western yellow pine are ordinarily scarred but survive. Reproduction of some species perishes with the lightest fire, while as shown by investigations of the Forest Service a comparatively large percentage of that of such trees as the longleaf pine survives but the growth rate falls off. Fire damage in the form of fire scars may permit the attack of wood-boring insects and fungus infection, which years after the scar is apparently healed are found to have taken a large toll of the merchantable value of the tree. By weakening the vitality of the tree fire may induce attacks by bark beetles which eventually kill the tree. Commonly the growth rate of single trees or entire stands is reduced by such damage. Investigations by the Yale Forest School have shown that the eastern hemlock is a desirable tree in some hardwood forests but that it is frequently eliminated by fire to which it is very susceptible. Stands may be partly killed and the resulting débris furnish fuel for severe future fires.

The damage to the forest may also include injury to the soil, the soil humus, or the soil life. Conflagrations may seriously disturb the balance of forest life, both of rodents and larger animals. Ground cover may be destroyed and reduce the carrying capacity of livestock, or it may be stimulated and retard forest reproduction. The soil may be laid bare and thereby be made much more susceptible to erosion. As a result streams and reservoirs may be silted and floods damage and destroy property miles away. Finally, a series of fires may lead to the creation of nonforest areas, many examples of which exist in practically every forest region of the United States, on which trees cannot be replaced except at high cost by artificial planting.

Since the recognition and exact definition of physical damage from forest fires is so exceedingly difficult, chiefly because much is not apparent even on close inspection or is very remote in time or distance, research must pave the way and outline the methods for later administrative practice. Exact statement of the damage in dollars and cents is equally difficult. Take, for example, the destruction of forest reproduction in a remote forest region, where now even the mature stand has a low sale value, or the case of soil erosion and silting and flood damage.

Investigations of damage by forest fires which have been made or are now under way include those of the Forest Service on the fire-scarring of western yellow pine in the Pacific Northwest, of light burning in the pine stands of California, of the damage to hardwood and pine stands in the southern Appalachians and southern pine belt respectively, and the relation between fires and chaparral and erosion in southern California.

The State of California has made a rather comprehensive survey of the relation between fire and erosion over other parts of the State.

Fire as an Agent

The preceding discussion has dealt solely with the destructiveness of fires and their prevention and suppression. Fire can and should in some cases, however, be used as an aid in timber growing. It will have to be employed for slash disposal in many forest types. The Douglas fir stands of the Pacific Coast, where slash and débris from logging often lie several feet thick, illustrate an extreme. The hazard is so great that sooner or later fire is almost certain. The problem is to burn in such a way that a new forest can be secured by natural processes. In other cases the germination of tree seed is undoubtedly aided through destruction by fire of forest débris and humus, permitting the seed to reach the mineral soil. This is apparently true of yellow poplar germination. Still other cases may be found by research where controlled burning, when its effects are understood and methods are safeguarded, may be used as a beneficial agent.

Protection Standards

The justification for fire research is primarily in its necessity for timber growing. Satisfactory timber crops can not be grown unless certain definite standards or objectives of protection are attained, for instance, maximum percentage of area that may be burned over in any year or period. What those standards are must be definitely determined for all of our forest types and for different stages in the development of forest types, upon full knowledge of the damage fires will do, and this is a task best attempted by research methods. Unless every protective organization has such objectives it can have only vague and unsatisfactory ideas of what it must accomplish, of whether its attainments are up to the mark, and of whether its expenditures are unnecessarily low in the light of the values at stake, or excessively high from the standpoint of diminishing returns which to be safe and useful must be considered on the most comprehensive basis. Such standards are in fact the only means of fully relating protection from fire in effectiveness and cost to the silvicultural objectives which it is designed to make possible.

Additional standards or objectives in the form and effectiveness of organization which will insure the protection standards must also be set. Hazardous conditions must be predicted at least specified periods in advance. Fires must be discovered and reached within specified periods if they can not be prevented altogether. To attain the standards set at lowest cost there must be a proper distribution of protective forces and of potential suppression forces based in part upon thoroughgoing knowledge of fire risk in different parts of the area to be protected, fire behavior, and damage, and in part also upon an equally thoroughgoing understanding of the past performance of the protective agency. The latter requires the keeping of current and most critical analyses of comprehensive forest fire statistics. No protective organization will make much progress unless it keeps a statistical record of its performance and studies that record most intensively. Here again research methods will be most effective for the determination of standards, and for the basis and technique of hazard

and liability surveys, upon which the distribution of the protective organization must be based.

Important Progress and Future Work

Research in forest protection against fire has been confined very largely to the United States, and here it is an activity of the last decade. Finland alone of foreign countries seems to have attempted anything—largely the determination of the degree of correlation between the number of forest fires and the extent of rainfall, temperature and humidity. To summarize progress, in two or three regions the Forest Service has made preliminary studies of the combustion of forest materials. In several regions the prediction of critical fire weather is being attempted without, in most cases, very satisfactory definitions of what the most critical conditions really are. The Weather Bureau is now entering the prediction field on a much larger and more satisfactory scale. There have been a number of partial investigations of fire damage, but nothing as yet has been attempted in any region to cover the entire field. Equipment has come in for considerable attention in the aggregate, and pumps, fire-fighting tools, range finders, and spark arresters have been devised in considerable numbers. Intensive work, and probably in volume the most extensive, has been devoted to the analysis of the forest fire statistics available.

The work on prediction is largely that of the Weather Bureau independently or in cooperation with the Forest Service, while the latter has been attempting to define critical fire conditions. Purdue University conducted an intensive test on the throwing of sparks by locomotives and on the inflammability of sparks of different sizes. The work on equipment is that of many different agencies, including industrial concerns. The balance of what has been done is the product of the Forest Service. In this no attempt is made to include the rather large aggregate volume of semi-investigative studies by protective organizations, of their own organizations and results. The study of fire problems, which may properly be classed as research, now under way by all agencies in the United States, probably does not even now much exceed the full time of half a dozen men. This attack will have to be multiplied many times before any pronounced progress can be made in fire protection. Meager as it has been, however, in the light of our needs, the research already done has served to block out the fire research problem at least in its broader outlines, and here and there to give us invaluable information and background for administrative use.

Among the classes of research most in need of emphasis are widespread and intensive studies of the laws of combustion, which ought to be going forward in every important region of the United States. Closely connected with these should be the necessary supplemental research to carry the results through to the point of final practical application in fire suppression. The practically exclusive use of man-power in fire suppression, because of its excessive cost, justifies a comprehensive research program for the development of special equipment. In the same class from the standpoint of urgency should be investigations to define critical fire conditions and to pave the way for the prediction of such conditions so far as practicable, and other lines of investigations which will lead to the prevention of fires. Research leading to prevention is important because in

practically all cases the cost of prevention is only a fraction of the cost of suppression. Important also are investigations of fire damage which afford an invaluable guide in the determination of protection standards, a measure of the effectiveness of protection, and which are most valuable in driving home the real menace of forest fires. From this list can not be omitted the determination of protection standards themselves, for these in a way constitute a final expression based upon all research and experience of the results which must be obtained to insure profitable timber crops.

2. FOREST FUNGI AND MISTLETOES

The problem of fungus diseases in the United States is one of extraordinary difficulty. Disease and defect are rampant in virgin forests. Many trees of these stands are normally of great age, and far past maximum resistance. Disease for thousands of years has been one of the potent means of eliminating the old trees from the forest, and no known agency has tended to reduce it except fire, which in many cases has actually had the opposite effect. Lumbering has in most instances favored the spread of disease by removing the healthy and sound trees and the more resistant species and leaving the diseased and defective trees and the nonresistant species. The first quarantines to prevent the importation of forest disease from other countries were put into effect in 1912, and have in several cases of our most disastrous epidemics locked the barn after the horse was stolen.

The control of forest diseases should become easier as the age of the stands is reduced and their natural resistance is thereby increased, as the forests are gradually brought under management, and as cultural operations become possible which will remove defective and diseased trees or set up conditions favorable to resistance. Along with these possibilities will of course come increasing opportunities for special preventive and control measures.

This situation, in part future outlook, and in part inheritance from purely natural proccesses and from industrial operations which gave little thought to future forests and even less to disease, is the background against which a comprehensive program of pathological research must be set. Considering alike the inheritance of the past, present conditions, and the future outlook, the program should as its chief objective be designed to contribute to the growing of maximum timber crops by making it possible for timber growers to prevent epidemics and to minimize losses from disease by specially adapted forms of forest management or by other means. Necessary provision for domestic or import quarantines by public agencies can not be overlooked. Virgin forests must likewise be protected by prevention if possible. Effective methods must be at command for the minimizing or control of epidemics which do start in either virgin or second-growth stands.

The decay of wood after cutting is discussed under "The Utilization of Wood and Other Forest Products." The diseases of important forage plants, such as smut on brome grass, constitutes still another and entirely distinct problem.

Taxonomy, Ecology, Pathology, etc.

Full descriptions of forest tree fungi in all stages of development, a knowledge of their distribution, and finally their classification into species,

is the starting point for all investigations in forest pathology and all effective forest protection. Research of this character must include all classes of forest tree fungi—the juvenile damping-off diseases which take such an enormous toll of forest tree seedlings; the girdling diseases exemplified by the white pine blister rust, and the chestnut blight which now threatens to eliminate one of the most valuable species from our forests; the heart rots which reduce by almost unbelievable totals the volume of merchantable timber; still other classes such as the root rots, and leaf diseases, on which relatively little work has been done; and finally, the fungi which are beneficial rather than injurious. Illustrative of the latter class are some of the soil fungi, and those which destroy logging slash. This research must also include mistletoe.

The initial investigations of forest pathologists in the United States following European precedent were largely given to the description and classification of tree diseases, and the determination of their life histories, their preference for one or more hosts, and in minute detail to the description of their effect on the wood structure of their hosts. Although most essential for the initial stages, these in effect necessarily made the study of the fungi almost an end in itself. A fair start has been made in these classes of research during the last 30 years on the fungi of both the East and the West, chiefly by the Bureau of Plant Industry, but notably also by such agencies as the office of the Dominion Botanist of Canada, the New York Botanical Garden, the Pennsylvania Chestnut Blight Commission, and various individual workers.

More recently, however, as silviculturists and forest pathologists have recognized the essential unity of their problem, emphasis has been growing on research into the environmental requirements and reactions and the pathological relationship to the forest, making of forest pathology more and more an essential means to the main objective of the regulation, management, and growing of timber crops.

Obviously we shall have to know in full the life history of the forest tree fungi which occur in the United States, but their development must be studied in relation to environment. A better understanding of the relation to varying climatic conditions is necessary. We know something about the effect of wind movement on the spreading of white pine blister rust for instance, and in a very general way about the moisture conditions necessary for the germination of spores, but practically all the work on climatic factors is in the future. We still have much to learn about the processes and nature of the attack by many fungi, a question which in the East has been most intensively studied for the white pine blister rust and the chestnut blight. We must know the interrelation between fungi and insects and wounds in the living tree caused by fire, lightning, frost, logging operations, etc., in which most has been done in the pine-cedar-fir forests of California by the Bureau of Plant Industry.

We must investigate the relation of the whole underlying normal and abnormal physiology of the tree to the disease, and of the diseases themselves to the tree, subjects of great magnitude and importance on which little has been done. At what age are trees most likely to be attacked? Does the explanation lie in unknown physiological conditions or processes? Why is it, for example, that thrifty young trees escape for so many years the attack of the so-called heart rots, whereas with age and the formation

of heartwood they become susceptible? What connection, if any, is there between the prevalence of diseases and forest conditions such as vigor or decadence, mixtures or pure stands? What is the nature of immunity of individual trees and of races within species? Is it such that we can or should take advantage of it immediately in forestry practice, or at least in the breeding of strains in which it can be transmitted permanently?

What we need, in short, is a complete understanding of the life history of the fungus itself and its entire relationship with all other factors, climatic or biological, including with particular emphasis the pathological relationships with the tree host and the forest. The crucial point of all these investigations must be to find the weak spots in the fungus development or its environmental relationship, because it is at these spots that prevention and control measures must strike in order to have even a reasonable probability of application or possibility of success. While as yet little has been attempted on many environmental factors, the most striking examples of investigations undertaken from the pathological standpoint are those of the Bureau of Plant Industry relating to blister rust and chestnut blight, and those relating to the management of the National Forests.

As will be seen from subsequent discussions, the properties of wood on which its ultimate usefulness depends seem frequently to vary with the conditions under which the tree was grown in the forest. In time, requirements of this character will unquestionably influence our silviculture, if through research the necesary relationships can be worked out. It would be strange if pathological relationships did not enter into this to a greater or less extent, and in any case a well-rounded-out attack on the growing conditions and wood properties problem must include this field.

Damage

The program already outlined necessitates a study of character of damage caused by fungus diseases to individual trees and to the forest. It is also necessary, however, to understand damage from the larger standpoint of the amount and character of annual and periodical loss by species and types for entire forest regions and the entire country, and for this regional and national surveys are needed. The ultimate purpose is to get at the real significance of the losses, at a more comprehensive determination of the fungi which are actually or potentially dangerous, and of the tree species which are particularly susceptible, at the forest regions in which most research and control is needed, and in short, at the broad regional and national bearings of the whole question of fungus disease. Furthermore, surveys of this character must be more or less continuous, or provision should be made for their repetition periodically.

Such surveys combined with the investigations already outlined will, in regions where there are second-growth stands, afford some basis for the determination of the age or rotation at which species particularly susceptible to decay must be cut, the so-called pathological rotation. Possibly later this will be modified by the changed conditions of forest management such as the elimination of forest fires. Similarly they will give the full significance of the relationship between disease and loss from fire and logging scars, and thus indicate the need for control of factors which are the indirect causes of disease.

From their inception practically all of the investigations of forest pathology in the United States have contributed to the survey conception. This is true of the early work of the Bureau of Plant Industry in the eastern United States, of much of that in the western National Forests, and of work of State and national agencies on the blister rust and the chestnut blight. A few studies have, however, contributed more directly, notably those in the National Forests of California, the northern Rocky Mountains, and the Douglas fir region of the Pacific Northwest. Much of the work, however, has been primarily for another purpose, or from the survey standpoint has been fragmentary in character and limited in area. As a result a recent attempt by the Bureau of Plant Industry to round up all available data, invaluable though the conclusion, necessarily had a rather unsubstantial basis. Only systematic surveys can answer the purpose, and these, except for the instances mentioned, have so far been entirely out of the question for existing organizations. After standards and technique are worked out, these surveys are to a certain extent pure application, but unless the assistance of investigators in forest pathology is invoked in large measure, they will fall far short of their full possibilities.

Prevention and Control

Preventive forest pathology promises to be the cheapest and most effective. It is on a par with forest fire prevention, with the prevention of insect epidemics, and with preventive medicine. Some of the best possibilities of tree disease prevention undoubtedly lie in special adaptations of forest management, more and more of which will become feasible as forestry develops. In extreme cases pathological requirements may dominate silvicultural measures and will rarely be lacking under the most favorable conditions. Mixed forests of two or more species are usually more resistant than pure stands. Should we rely upon natural mixtures? Can they be improved upon? What limitations must be taken into account? Pathological rotations which cut trees before the age when heart rot becomes serious offer another potent method in cases such as the western forests containing incense cedar or white fir. What in each case is the critical age? What is the cumulative loss when this age is exceeded? What are the most desirable rotations considering potential growth in quantity and quality, losses from defect, and maximum financial returns?

Thinnings, improvement cuttings, and other cultural methods may be resorted to for insuring healthy, vigorous growth and incidentally for the removal of diseased trees. When under each special set of conditions should they be made? What trees should be taken out? The cutting of diseased snags offers obvious advantages. When is it advisable or necessary? The elimination of fire will unquestionably reduce the wounding of trees and the danger of heart rot. In what regions and for what species is it particularly important?

Pathological considerations should influence practically every regular cutting of a forest under management. What trees from the standpoint of disease can best be left for growth and for seed? What are the external symptoms of the kind and the extent of the heart rot or other disease which the forester can recognize and use? But these examples merely illustrate the kind of measures which investigators must work out

in a detailed specific way and for many different fungi and forest trees and types, carrying the fundamental research formerly outlined to the point of full administrative application. Progress to date is limited largely to the determination, in the California pine region, of the advantages of snag felling, the pathological rotations for incense cedar and white fir, and the relation of fire, lightning, and other wounds to decay; in the Douglas fir forests of the Northwest, to the advisability of leaving defective seed trees. This is the work of the Bureau of Plant Industry.

The removal of one host of alternate host fungi, as, for example, that of gooseberries and currants, a method which is being so extensively used in attacking the white pine blister rust, may be either a preventive or a control measure. This measure is based on years of research by the Bureau of Plant Industry and on certain earlier research in Europe. It is one of the most striking examples in the United States of investigations of a disease from the standpoint of the pathology of the forest, carried through to the point of practical application. It illustrates the special measures which may have to be developed for other diseases.

Domestic quarantines and those to prevent the importation of foreign diseases must be resorted to in many cases, but to be most effective and at the same time not unnecessarily harsh, they must rest on intensive knowledge of both fungus and hosts. Full protection from quarantines is made enormously more difficult by virulent attacks on American species by some diseases not particularly serious in the case of original hosts. The chestnut blight is an example.

Nursery practice has its own peculiar needs for prevention and control of such diseases as damping off. Merely the fertilization, watering, and shading of the nursery beds may be necessary to stimulate vigorous and hence resistant seedling growth. In other instances fungicides may be required on the soil or the growing stock, but in practically all cases the determination of what is necessary and best has been found to depend upon research or long years of trial and failure through ordinary commercial practice. Methods of prevention and control have been worked out by the Bureau of Plant Industry for the half dozen species now grown in quantity for artificial planting in the United States.

Finally, use might be made of races found to be immune, or those which are developed through genetics. The problem would remain of determining the conditions and limitations of such use.

Beneficial Fungi

Not all forest tree fungi are harmful. Advantage may be taken of those saprophytic fungi which destroy the slash and débris from logging and under some conditions may or should be depended upon to make the use of fire unnecessary. For the western yellow pine stands of the Southwest the Bureau of Plant Industry has determined the conditions under which slash will decay most rapidly, and similar work on a small scale has begun in other regions. Following European leads other groups of beneficial fungi will undoubtedly be found in the soil, the growth and development of which can be encouraged by the proper forms of forest management. This alone will probably prove to be a very large field on which even the beginning is still to be made. Pathologists must first

ascertain, however, what fungi are beneficial and under what conditions they are most active in the decay of slash or otherwise most beneficial.

Mistletoe

Investigations of the mistletoe have so far been largely taxonomic, although they have been carried somewhat farther by the Bureau of Plant Industry and the Forest Service in the western yellow pine forests of the Southwest, and similar work has begun in California. Much the same field as that outlined for fungi should be covered.

Outstanding Progress and Problems

To date research in forest pathology has chiefly to its credit in the United States:

Substantial progress in the taxonomy of tree diseases, and in the determination of the effects of rots upon the wood of trees;

Equally substantial progress in the life histories and the pathological relationship to their hosts of the chestnut blight and the blister rust;

The working out of special silvicultural adaptations in the forest management of a few western forest regions, but chiefly the pine forests of California;

The development of special measures of control for the damping off of seedlings of the few species now largely planted, and for the blister rust.

The outstanding research problems of the future in a national program are:

The determination of the life histories of fungi with particular emphasis on environmental factors and physiological and pathological relationships to the tree and the forest;

The development of preventive and control measures based on special pathological adaptations of forest management and of special measures to prevent the importation of foreign diseases;

Regional and national surveys of pathological damage, which can become more and more effective as the knowledge of all classes of fungi is increased;

Soil fungi and their proper place in silviculture.

In carrying out this program, research should be carried as rapidly as possible into important forest regions such as the southern pineries, the central, Appalachian, and southern hardwood forests, and the Lake States, which as yet have hardly been explored. It should also take up important classes of diseases not yet thoroughly studied, the leaf fungi, mistletoes, and root rots. More and more it should be concentrated on the second-growth forests which are being brought under management.

3. FOREST INSECTS

Forest entomology is still in some western forest regions almost entirely a problem in the protection of virgin forests. In the East, however, where unregulated cutting and fire has resulted in more or less satisfactory second-growth stands, forest entomology is becoming a phase of forest management. Gradually the latter condition will become true for the entire country as second-growth forests succeed virgin stands and are placed under increasingly intensive management. The transition may tend

to minimize some insects now great menaces; for example, the western pine beetle, on which some of the largest control measures are now concentrated, and which seems to prefer mature and decadent timber. While violent disturbance or removal of the virgin forest may minimize some problems, it is already intensifying others such as the budworm invasions of the spruce-fir forests of Maine and the Lake States. Likewise a serious situation threatens in the jack pine forests following vast increases in the area occupied by that species after cutting and fires in stands of white and Norway pine. The transition may accentuate still others such as the southern pine beetle, which has been particularly severe in late years in second-growth stands. Already the United States has its full share and more of seriously dangerous imported insects such as the gypsy and browntail moths.

A national program of entomological research must be formed in the light of the transition now in process from virgin to second growth, and from uncared-for to managed forests. In general the program must be so formed that its results will enable the timberland owner to prevent infestations by suitable adaptations of forest management. Public agencies must be enabled to prevent the spread of dangerous infestations through local quarantines and the introduction of foreign epidemics through import quarantines. It must become possible to recognize the danger of serious outbreaks in their incipiency so that preventive measures can be applied effectively in the early stages. Control measures must be developed which will prove most effective at least cost in the suppression of serious infestations which do start. All of these measures must be related to the primary purpose of growing timber.

Those insects which attack wood instead of the living trees are discussed under Forest Products. Those which subsist upon the subordinate forest vegetation constitute still another group.

Taxonomy

As in other similar investigative fields, the first necessity in investigations of forest insects as well as in the application of the results is description and classification. Description must obviously cover all stages of development, which in insect life are so frequently complex and obscure. This work and supplemental classification must include all of the destructive insects such as the bark beetles, the wood borers, bark lice, and the defoliators. It must also include beneficial parasites and predators. Although still far from complete, this is a field in which most work has been done in the United States, largely by the Bureau of Entomology and chiefly on the very destructive bark beetles of the genus *Dendroctonus*.

Ontogeny, Ecology, Etc.

The life histories of all species of both injurious and beneficial forest insects must be worked out, a task of great complexity and infinite detail, requiring for years the work of many investigators. Although a fair start has already been made, chiefly by the Bureau of Entomology on the more important species, much remains to be done even on these forms. Comparatively little is known, for instance, of the life habits of the southern pine beetle between periods of epidemic infestations when it seems to keep entirely out of sight, whereas a more detailed knowledge of such

features might easily afford much more effective methods of prevention or control. Considerable work has been done by the Bureau of Entomology and a number of State and other institutions such as the agricultural departments of Connecticut, New York, Massachusetts, New Hampshire, and Vermont on the introduced gypsy and browntail moths, and by the State Forestry Department of Maine and the Dominion of Canada on the spruce budworm. The University of Minnesota has worked on the budworm and the larch sawfly.

The problem of periodicity of insect infestations lies at the heart of all preventive and control measures and should be attacked from the standpoint of its nature and of its fundamental causes. These cycles extend from the normal or endemic infestations which take each year from the forest a relatively limited number of trees, through the epidemics which may cover vastly larger territories than forest fires with corresponding destruction. Since they differ for all insect and tree species, it is rather a series of problems. On them only the barest beginning of investigative effort has been made and that almost entirely by the Bureau of Entomology, but enough to permit surmises of the sort indicated in the following paragraphs.

Climate is undoubtedly one of the causal or environmental factors in periodicity. Insect periodicity may be affected directly through seasonal or other variations in temperature, precipitation, and radiation. For instance, the mountain pine beetle seems to be particularly susceptible to the drying of the bark and little emergence takes place in lodgepole pine stands of the northern Rockies in the portions of the tree above the snow line.

Or climatic conditions may act indirectly through modifications in the physiological conditions of the tree. Drought may, for example, modify sap density, and this in turn determine the emergence of bark beetles and the virulence of their attack. It may be something of this nature or some other wholly unknown variation in the life conditions or processes of the tree resulting from drought which stimulates or permits the phenomenal increases characteristic of the southern pine beetle.

Still other factors may account for abnormal physiological or other conditions of the tree which contribute to or dominate the insect epidemic. It may be site or age. The attacks of the western pine beetle are apparently more severe on the poorer sites as they are also on overmature and decadent trees. It may be reduced vigor from overcrowding. Spruce budworm epidemics are especially severe in stands whose vigor and rate of growth have been lowered by density. Infestation or immunity may depend upon whether the forest is mixed or of a single species, or upon the proportion of mixtures. An excessive proportion of balsam fir may be one of the initial causes of budworm epidemics in the spruce-fir forests of the Northeast. The dominating factor in mixtures may be simply abundance or absence of food supplies, or it may go far more deeply into obscure effects upon the vital life processes and conditions of the trees themselves, but no one is certain.

Still further we need information on the secondary effects upon insect periodicity and infestations, of forest fires and of lumbering operations, through their initial modifications of forest conditions, and of the physiological conditions and processes in forest trees. There may be other

forms of immunity of individuals or races within species which have become hereditary, as apparently, for example, that of the Black Hills form of the western yellow pine to the Nantucket tipmoth in Nebraska sandhill plantations, which may be only a question of the size and pitchiness of buds. But in general little or no effort has been made in investigations or otherwise to take advantage of immune races which may already exist, and no effort has been made to breed immune races or to produce immune stands.

If we knew the extent to which in virgin stands forest insects were responsible for forest type succession, and for the composition of the climax type, it might add considerably to the clarity of our silvicultural measures. Entomologists believe from general observations that in some of our western forest types insects have in fact been an important or in some cases the controlling factor, but the question has never been studied intensively.

Finally there is the problem of parasitism and the life histories and environmental relationships of parasites and predators to forest-destroying insects, which if fully understood might in some cases offer the most practicable or the only means to forest protection. This is in itself a large field of fundamental importance and of greatest promise, as the results obtained by the Bureau of Entomology on browntail and gypsy moths show so conclusively.

Implied more or less clearly in the preceding and obviously dependent upon an understanding of periodicity and its causes are criteria indicating when epidemic infestations are about to begin, and thus affording a basis on which control measures could be timed. Equally valuable would be corresponding criteria of the approaching end of epidemics which might make further expenditures in control unnecessary. As yet we have little or nothing of either.

Although the life histories, periodicity, and environmental relationships of forest insects offer an enormous field for basic research of outstanding importance, only a small beginning has as yet been made in this field despite years of work, and that chiefly on the life histories of a relatively few of our most troublesome insect pests. We must know the life histories, the entire physiological relationship of forest trees and insects, the nature and causes of periodicity, the pathology of the forest in insect diseases, and the only means is through research which goes back to the fundamental life processes of both kinds of organisms. Out of greatly enlarged future investigations in this field must come such a grasp of this variable and complex group of relationships that the weak spots in both life history and environment of forest insects are recognized, for prevention of serious epidemics if possible, and for control if necessary.

Damage

The comprehensive program of investigations already outlined will obviously furnish information on the character of the damage caused by various forest insects to the trees which they attack. Estimates and evaluation of damage, however, can not stop there. Regional and national surveys must afford information on aggregate losses from the trees killed, the slowing down of growth, and on disturbances to proper balance in forest types, the increases in the fire menace through large increases in the

amount of dead forest material. Comprehensive surveys of this character should bring out the full significance of annual and periodic losses. They should conclusively determine the dangerous or potentially dangerous species of insects. They should awaken the timberland owner to the need for those adaptations of forest management which take the insect menace sufficiently into account. They should likewise awaken the public to an appreciation of a largely unnecessary drain on the forests of timber which we can ill afford to lose.

Timberland owners in Maine, in cooperation with the State and the Bureau of Entomology, have estimated the losses from the recent budworm epidemic. General estimates have been made by the Bureau of Entomology for all insects over the entire country but from necessity upon a very fragmentary and unsatisfactory basis. Systematic surveys repeated periodically are badly needed. To such surveys investigators in forest entomology must make large contributions.

Prevention and Control

The preventive measures which can practically be employed against the attack of forest insects are under present conditions very drastically limited. Undoubtedly one of the most potent wherever its use is feasible is such management of the forest that conditions adverse to the beginning of epidemics are maintained. Investigations to determine what such measures should be must start where those already discussed under ontogeny and ecology leave off, and supplement and round them out to the point of final application. Such management may involve the growing of mixed rather than pure stands over large areas; for instance, the conversion of the pure jack pine stands of the Lake States into white and Norway pine mixtures where the soils permit. It may even involve the control within mixtures of the percentages of critical species, such as balsam fir in the spruce forests of the Northeast. But we need to know what percentages may safely be allowed. The Bureau of Entomology has been investigating the relative immunity of different types of forest stand, or mixtures, in New England from attack by the browntail and gypsy moth.

Cultural operations, such as thinnings to insure a vigorous growth, may also be required, as again in northeastern spruce stands for protection against budworm attacks when thinnings would hardly be possible from any other point of view. Where is the danger point and when should the thinning be made? Possibly in some instances barriers may be justified similar to the moth-free zone now being employed in New England and New York to restrict the spread of the gypsy and browntail moths. Full knowledge of insects and their environment may disclose many simple methods as illustrated by the locust borer from which relatively dense plantations, in which the trunks of the trees are shaded, promise to be immune, whereas open plantations through which the sun can strike the trunks of the trees are severely attacked. Plantations should wherever possible take advantage of immune strains and races where trees are subject to attack. All of these relationships, however, depend absolutely upon the knowledge which only the research which unfortunately is now only barely beginning can supply.

Silviculturists need much more information along the preceding lines and much additional for which they can only look to investigators in forest

entomology. The extent to which such practices as light burning may be allowed in forest management without incurring the danger of insect attack is a case in point. Work of the Forest Service in the pine stands of California seems to indicate rather serious increases. Another is the reservation from cutting of trees for seed or future growth which are mostly likely to be immune from insect attack. Upon proper reservations in such cuttings may depend the success of an entire silvicultural operation.

Parasites and predators may with proper knowledge be used for prevention and may sometimes be found the only feasible method of control. For introduced pests it may often prove necessary to obtain parasites from the original home of the insect which it is desired to control. Little in this direction can be done successfully without research, as shown by the work of the Bureau of Entomology in cooperation with various Northeastern States on the gypsy and browntail moths. Parasites and natural enemies of these insects have been introduced. Years of careful study and experimentation have been required both in the United States and in the native homes of the pests to determine the habits and seasonal history of each beneficial species so that they could be imported and colonized intelligently and so as to prevent the introduction of any secondary parasite that might undo the work of the primaries. Experience has shown that no one species of parasite can effectively control the gypsy moth, but a combination of several differing in habits and methods of attack can if they increase to their maximum exert a potent influence. The increase in some of the species has been relatively slow following colonization. Many species were not adapted to the conditions in this country and did not survive. Much progress has been made in research and greater results are anticipated.

Mechanical methods, of which cutting or barking of trees are examples, may be essential in some cases, although the extent to which those so far developed are effective is uncertain despite several years of cooperative effort on western species by the Bureau of Entomology and a number of other agencies. Effective insecticides can in forest practice be used only in the nursery and must ordinarily be determined separately for the different sets of conditions under which they are required. Several have been developed by the Bureau of Entomology for the species now commonly used in planting, but any enlargement in the number of species may require additional insecticides.

Quarantines offer problems of their own, in part because of the widely different ways in which insect pests may be distributed. Import quarantines require detailed knowledge of dangerous insects in foreign countries, but one of the chief difficulties lies in the fact that a species seemingly harmless under its native environment may become a veritable scourge under foreign conditions. The Japanese beetle, which defoliates forest trees in its destruction of practically every form of plant life, unfortunately promises to fall in this class.

Greatest Progress and Problems

The handful of investigators who have worked on problems in forest entomology have accomplished much in the face of great obstacles, not the least of which have been a general indifference to their work and lack of appreciation of its importance. Greatest progress to date has

been in description and classification of forest insects and the determination of life histories, chiefly of the enormously destructive bark beetles and a limited number of others such as the spruce budworm and the introduced gypsy and browntail moths, and also in methods of combating these moths through enemies and parasites and otherwise. The great problems of the future are the fundamental investigations underlying periodicity, the fundamental relationships between insects and silviculture, the forest pathology of insect diseases, with prevention of infestations chiefly in view, and feasible, thoroughly effective methods of control. More and more the problem will become one of second-growth managed forests. Altogether it is difficult to overstate the magnitude and the urgency of the national requirements for research in forest entomology.

4. OTHER FORMS OF PROTECTION

While protection from fire, forest fungi, and forest insects is of greatest importance, other forms of damage are already compelling attention and will become more and more significant as our forests are placed under intensive management. For the greatest simplicity of treatment most of these miscellaneous forms are discussed in other sections of the report.

This is true of protection from climatic agencies, wind, snow, hail, and sleet, the frost heaving of seedlings, sunscald, and avalanches, which have already been covered under silviculture.

It is also true of the protection of forest reproduction from livestock grazing, and of protection of seedlings and the larger trees from mice, squirrels, wood rats, porcupines, deer and other forms of forest life, all of which are taken up in the following sections.

This leaves for consideration here only protection from gases, smoke, smelter fumes, etc. Smelter fumes have already become a forest problem in a number of localities in the United States. Ways and means more or less successful to combat them have resulted. Research from time to time will be necessary as special cases arise, although it is unfortunate from many points of view that the operation of destructive agencies and the actual destruction of forests seems invariably to precede research looking toward prevention.

FOREST INFLUENCES

Probably no other effects of the forest play a more important part in human economy and have attracted greater popular attention than has its influence upon the climate, soil, the regularity of streamflow, and erosion. The forest tends to ameliorate climatic conditions by reducing extreme high and low temperatures, enriching the air with oxygen, reducing the atmospheric dust, and through these, improving human health conditions in general. It serves also as an abode for wild life and birds. It is one of the important factors in building up soils. The forest cover is an active influence in increasing the precipitation over the area occupied by the forest, retarding the melting of snow, lessening direct evaporation from the soil, maintaining springs, reducing surface run-off, and preventing erosion. As a matter of fact, it is primarily because of the accepted facts of the influence of the forest upon streamflow, which have been emphasized

by the progress of forest denudation, that legislation for National Forest acquisition and administration has come into existence.

These phases of the influence of the forest have long been under discussion, but so great is the difficulty of observing them with precision, and so wide the range of economic interests affected, that considerable divergence of opinion still exists regarding them.

Research Done or Under Way

As on many other subjects which have wide popular interest a voluminous literature has sprung up, some with good scientific foundation, some based on rather superficial and not thoroughly verified observations. To get at the bottom of this subject, systematic studies on a nation-wide scale extending over a long period of years are needed. This so far has not been attempted in this or any other country. There have been a large number of observations dealing with this or that phase but no organized effort to solve the problem as a whole.

A number of years ago the University of Nevada conducted a study of the influence of forests on the drifting and melting rate of snow. The Forest Service has made a similar but less exhausive study on the melting of snow in Oregon. The Weather Bureau and the Forest Service have had under way since 1909 in Colorado an intensive investigation of the influence of the characteristically open forests of that region on both streamflow and erosion. The Forest Service has made a similar but less intensive study of the influence of chaparral in southern California. It has in process in the high mountain parks of central Utah a long-term investigation of forage cover and erosion which will be referred to again in the discussion on forest range management. Studies have been made by the Forest Service in Arizona of climate in the forest and in the open mountain parks, and in the Northwest of the influence of the forests on avalanches.

An ingenious theory of the rôle of forests in the path of prevailing moist winds has been advanced in this country and applied to the eastern part of the United States and the Pacific Coast. This theory, however, is based, not on actual quantitative measurements, but on a few fairly well-established meteorological and physiological premises. If this theory holds under systematically arranged meteorological observations, the part which the forest plays in the precipitation over wide continents may appear in an altogether new light and its influence assume tremendous economic possibilities.

An individual investigator has looked into the relationship between forests and the water level in wells in Illinois and Indiana and the surrounding States. A similar study by the University of Iowa has indicated the relation between the water level, the flow of springs, and the presence or absence of tree cover. The Geological Survey has also, in connection with the acquisition of land for National Forests, made many general investigations of the relationships of forests to navigable streams, and has published a contribution on the importance of the forest in preventing erosion in the Southern Appalachians. The University of Wisconsin has published a bulletin on the factors, including forests, which modify streamflow in that State. Considerable work by the Middle Western agricultural colleges and by the Forest Service on the influence of shelter-belts and windbreaks in the protection of farm crops has led to

very concrete results. A little fragmentary work based largely on European precedents has also been done by various agencies on sand dune fixation by forest plantations, among which the work in Golden Gate Park in San Francisco should be mentioned.

Important Problems of the Future

One of the outstanding groups of problems which will require much additional attention centers around the influence of the forest on streamflow. Possible elimination of excessively low or high water stages are involved where navigation, water power, and irrigation are vitally concerned. An understanding of this group of problems necessitates such investigations as the quantitative measure of transpiration by forests, the effect on soil water of the absorption by tree roots, the amount of precipitation which is prevented by the forest cover from reaching the ground, the holding back of water by the forest litter, other ways in which the forest retards run-off, as well as finally the actual regimen of streams on forested and denuded watersheds.

A somewhat related group of problems which again is the aggregate of a large number of separate relationships, covers the influence of the forest upon the water level of an entire district. In regions such as southern California, where much of the irrigation water is obtained from wells, this water level may be of great importance. The problem in which both high forests and chaparral forests are involved is to maintain conditions which will put as much water as possible under ground for later use in irrigation. This group of problems runs into much the same kind of investigations as those indicated for streamflow.

A third group of problems of fully equal importance relates to the function of forests in preventing erosion. Such questions as the following require investigation: the physical or mechanical effects of tree roots in binding the soil; the holding back of torrential run-off from rain or melting snow, by forests and forest litter, so that erosion does not start; and the total erosion from similar watersheds one with and the other without forest cover.

A fourth group of problems includes the direct influence of the forest upon climate, including local precipitation, atmospheric moisture, air and soil temperatures, all of which have a bearing on silvicultural systems, the maintenance of moisture conditions, and the reduction of fire danger; and possibly on the vigor of the forest itself and its susceptibility to attack by insects and fungus diseases.

Other problems should by no means be excluded but will probably be of relatively local importance. Among these will be additional work on shelterbelts and windbreaks in the Middle Western plains and the larger valleys of California, on the prevention of avalanches, and on sand dune fixation. Many of the problems which are directly or indirectly those of forest influences have been or will be outlined elsewhere. They include influences on the fertility of the soil, upon forest vegetation for livestock grazing, upon wild life, and upon recreational use.

It will be seen that a group of peculiarly fundamental questions runs more or less continuously through all of the major and most of the minor problems above outlined, such as the effect of the forest upon the atmosphere and climate, upon soils, and upon the water regimen of streams

and localities. Although the fundamental relationships may be identical, the final answer will not be quite the same for any two sets of conditions of forest subordinate vegetation, soil, topography, and climate, because of the complexity of the factors involved.

Investigations of forest and forage covers must for one thing be coordinated, since both are factors in the total influence. Investigations of local sets of conditions must serve as the basis for such special adaptations of forest management as protection forests, in which no cutting is allowed; still others in which very light cutting may be permitted which will never destroy the forest conditions necessary to hold the soil; control of grazing which will prevent the destruction of the forage cover; special plantations designed to retard the melting of snow. Investigations must have as a background the particular service which it is desired to have the forest render; the prevention of sheet erosion in the southern Appalachians; the maximum summer flow of streams in irrigation districts; constant levels or at least the elimination of very low water stages in navigable rivers; both the prevention of erosion and stream regulation in the agricultural districts of southern California where management must be largely of chaparral rather than of high forests.

Most investigations of influences will require the collection and analysis of an enormous amount of data on climatic factors, on the periodicity and amount of streamflow, and on the character and amount of erosion. Altogether for one reason or another the problems of forest influences are of great importance and we must look forward to many years' work on them in practically every forest region of the United States.

FOREST RANGE MANAGEMENT

Although the production of timber must be the chief objective in the use of forest lands, other products of great importance can and should be obtained. Forage is unquestionably one of the most important of these. It can under many forest conditions be made to serve as the basis for a large and important livestock industry without reducing timber production. Under other conditions it may be found that the two forms of use cannot be reconciled and that it will be necessary to choose between them. Under still other conditions intensive forestry will produce such dense stands that forage plants will not be able to grow in competition.

Forage conditions differ as widely as the forests with which they are so intimately associated. The western forest ranges, which are similar in many respects to the arid and semi-arid treeless ranges with which they are intermingled, present very distinctive problems of range and livestock management. The farm woodlots of the central hardwood region constitute another extreme, and the southern pineries a third. In still other forest regions, such as the northeastern spruce, profitable livestock grazing is hardly a possibility.

Forage, the basic resource for forest grazing, is practically identical with the subordinate vegetation already referred to under Forest Management. Much of the fundamental information required for all regulated forage use is also necessary in timber growing, so that on the ground much is to be gained by carrying forward together, to a certain point at least, investigations for both purposes. But it is clearly necessary to work

out separately with greater intensity some additional problems which influence directly phases of timber growing practice and other phases which influence range regulation.

1. FUNDAMENTAL INVESTIGATIONS

Taxonomy of Range Vegetation

Either in connection with the study of the range vegetation for grazing or of the subordinate vegetation for timber growing or for the two forms of utilization combined, the grasses, weeds, and shrubs, must be classified and described. For grazing this work must be particularly intensive on species, such as blue grama, which because of abundance or high food value are important as livestock feed, on those which are mechanically injurious like the so-called "rip gut" of California, on those which are poisonous like water hemlock, and on those which are aggressive but worthless, such as the snakeweed. This work must eventually cover the entire forest area of the United States where subordinate vegetation is likely to be of importance for either grazing or timber growing or both. The distribution of species must also be ascertained.

Taxonomic research of this character has been under way for years by many university botanists in all sections of the United States and is still going on. About 20 years ago the Forest Service in cooperation with the Bureau of Plant Industry began a systematic attempt to cover the National Forest ranges, consisting of some 90 million acres, and the task is now possibly half done.

Ontogeny

Either for grazing or timber growing, or for both combined, it will be necessary to study the ontogeny or life histories of individual species in the subordinate forest vegetation. Blue grama in the Southwest, for instance, makes but little growth until mid-summer rains become heavy. Full stocking of the grama ranges for the entire season may cause losses of livestock from starvation and injury to the range in late spring and early summer unless feed produced the previous summer is available until new growth becomes sufficient. The mountain bunch grass of the Northwest is extremely palatable, and since it does not mature and disseminate its seed until August or September, it is necessary, if the stand is to be maintained, to defer grazing until late August or September at least once every three or four years.

Some work on life histories of forest range plants has of course been done by university botanists. The Forest Service has some information on more than 6,000 species native to the western National Forest range, for some 3,000 species of which much more thoroughgoing data have been obtained. Work other than this on life histories has concerned primarily the poisonous range plants, in which the Bureaus of Plant and Animal Industry have led. The work in general is now going forward actively, but there is still an enormous job ahead in the National Forests alone and a large additional area must eventually be explored.

Physiology

Sooner or later knowledge of the physiology of forage plants will become necessary for the best development and utilization of forest ranges

and probably for the successful handling of the forests themselves. From the livestock growing side it may, for example, be necessary to understand life processes for a better realization of comparative food values as between species and of the same species in different stages of development. Similar work will undoubtedly be necessary also on poisonous plants.

Ecology

The ecology of the subordinate vegetation concerns both the forage and the timber crop equally up to a certain point, and then as in other lines of research may have particular phases which influence timber growing and grazing, respectively. Plant association development and succession of the subordinate forest vegetation has been and is now being studied by many university ecologists in the East, although most of the field is yet to be covered. Comparatively little has been done in the South, and that attempted in the West by the Carnegie Institution and the Forest Service with a small amount of additional work by universities and colleges has centered at a limited number of places. The University of California has recently initiated important work. Practically the entire question of association development and succession, however, and particularly the competition between species under the conditions prevailing on specific areas, still awaits investigation. Its importance may be indicated by a single example, in which the Forest Service found in central Utah that the climax and highly valuable wheat grass type could be retained only under proper range management. Excessive grazing resulted in lower successional stages of much less value.

The climatic relationships of forest range vegetation have received a little attention by the universities, although not nearly as much as association development and succession. The Carnegie Institution has studied this relationship intensively in the central Rocky Mountains, and the Forest Service in a single locality in central Utah. The Bureau of Plant Industry has made an important contribution on the water relationships of non-forest range plants which indicates that there may be considerable variation in the water requirements of those found within timbered areas. The Forest Service has also studied the wilting coefficient of certain range plants in eastern Oregon and in central Utah. Very general climatic relationship work has been done in many locations by a large number of agencies. The work is so important and the results so essential to a proper interpretation of many other investigative results that thoroughgoing fundamental study of all the climatic factors in all the main regions is requisite to the ultimate solution of both the timber growing and range management problems.

Soils, a third environmental factor, has received the least attention of the three, since a small number of general surveys comprise practically the entire work done. Here as in other fundamental forest research much of the work to be done should solve problems in both timber and forage production. A large number of variable soil factors, structure, composition, water relations, humus, life, etc., have already been discussed under Forest Management and need only to be referred to here; but it should be recognized that the number of plant species involved in the subordinate vegetation is vastly greater than in the forest itself.

Studies of the reaction of a few individual plants and associations to

various intensities, times, and degrees of grazing and to clipping simulating grazing have been made by the Forest Service in different parts of the West. Some work of a similar character on non-forest plants has been conducted by the Bureau of Plant Industry and several State Agricultural Colleges. Grazing tends to place the more palatable species at a disadvantage with those of low value by reducing the vigor, size, food stored in the roots, and amount and viability of seeds of the more palatable plants. The problem is complicated by the fact that the same species react differently with variation in ecological factors such as soils. The problem is partly one of an ecological balance disturbed by grazing, and partly one of the physiological reaction of the plant, and will need to be studied fundamentally for all important species and associations. Work on this question affords a key to many of the problems of forest range management.

Biological Relationships

A large number of biological relationships on which up to the present time practically nothing has been attempted will eventually have to receive much attention. In this class are rodents and game, to be discussed later in more detail, and a large number of insects and fungus diseases. An example of the latter is the smut which attacks brome grass. Investigations of this order will demand more attention as the need for livestock dependent on the forage resource grows and it becomes necessary to increase forage production to a maximum.

Fire

Forest fires influence usually for the worse the composition of forage plant associations, the soils which support them and the forest growth with which they associate, and cannot, therefore, be left out of account. In some parts of the country, however, especially in the South and California, it is the general practice of stockmen to burn the range periodically in the belief that it will improve grazing. The need for close correlation in the fundamental work which bears on both forage and forest is obvious. In protection from fire forage is involved along with timber.

Food Values

The food values of forage plants may be determined by three methods. The first assumes that the actual consumption of the forage by livestock is a criterion of food value. Under this method the Forest Service has for several years been making very extensive field observations under many different conditions on the western National Forest ranges and these observations have been fairly well correlated. While a very good start has thus been made on the National Forest ranges, the bulk of the work even there remains to be done. Relatively little research on forest ranges in other parts of the United States, beyond the most general observations, has been attempted by any agency.

The second method is by chemical analyses. Possibly 25 per cent of the more important western range plants have been analyzed chemically by the Bureau of Chemistry, working in cooperation with the Bureau of Plant Industry and the Forest Service, or by various State agricultural experiment stations, but these analyses have not as yet been tied in closely

with actual food values. The third method, by actual nutrition tests, would obviously afford the most conclusive results, especially when correlated with the preference shown by livestock on the range, but excepting poisonous plants nothing as yet has been attempted for range plants.

Of poisonous plants the Bureau of Animal Industry and the Bureau of Chemistry, and a number of agricultural colleges, have through chemical analyses determined the poisonous principles in the more important western species which are suspected of being poisonous. The determination of the exact difference between species and similar work on a great many minor plants calls for considerable additional inquiry. In addition the Bureau of Animal Industry, the University of Nevada, and to some extent also other agricultural colleges, have been and still are making feeding tests with poisonous plants, and those suspected of being poisonous. General treatises on poison plants within States have been published by a number of State agricultural colleges and an individual investigator has issued a comprehensive "Manual of Poisonous Plants."

Genetics

It is easily possible that strains more promising in food values, reproductive capacity, recovery from grazing, or other advantageous characteristics can be developed through selection and breeding experiments with the best native forage species. This is an important field for fundamental work on which as yet nothing has been attempted for forest plants, although selection and breeding investigations of introduced cultivated forage plants, particularly for drought-resistance and superior forage production, have been conducted by the Bureau of Plant Industry in cooperation with a number of agricultural colleges on the Great Plains adjacent to forest ranges. Closely related and in fact a part of the same field is the possibility of hybridization.

Exotics

The introduction on the western forest ranges of superior foreign species has been receiving some little attention from the Forest Service, the Bureau of Plant Industry, and some of the State agricultural colleges. The Carnegie Institution has under way investigations of the possibility of introducing exotics into the high mountain meadows of the Sierras. Most of the more valuable forage plants of the southern pine belt, such as lespedeza and the Bermuda grass, are in fact exotics. Alfilaria unassisted has spread widely on the California and Arizona ranges, and blue grass is reported to have spread remarkably in the Upper Pecos Valley of New Mexico. Although depleted meadow areas have been improved, little success has so far attended the efforts on the semi-arid western ranges. This is a field that ought to receive much more attention. As the floras of other countries are studied and the environmental relations of American forest ranges are better understood, introductions of the greatest economic value may become possible.

Influences

Under some conditions at least it is almost certain that the retention of the more valuable parts of the soil and the prevention of disastrous

erosion, silting, and stream damage depend largely upon the tree cover. In some cases the problem of forage influences and hence the research which it involves, is an essential part of the more inclusive forest influences, but in many parts of the western mountains treeless parks are large and frequent, and the influence of the forage cover is distinct over areas of considerable size.

The watershed of the Roosevelt Reservoir, which irrigates approximately 215,000 acres of valley land in southern Arizona, is being seriously injured by erosion which is probably resulting in large measure from excessive grazing during the drought of recent years. The depletion of the vegetative cover which should constitute a protective covering threatens to shorten materially the life and usefulness of the reservoir, upon which millions of dollars of agricultural and of urban development are dependent.

The Forest Service has conducted an intensive investigation in one situation in central Utah during the past 12 years to ascertain the true relationships on non-forested alpine lands between the forage cover and erosion and streamflow. The vegetative density of the forage cover has been varied through grazing by series of years. It has been found, for example, that an increase in the vegetative cover from .16 to .4 density reduced summer surface run-off about 55 per cent, and erosion approximately 56 per cent. This project will probably have to be continued for at least ten years more. The Forest Service also has under way a southern Arizona project on the management of brush land to develop a form of use which will not damage watersheds. A forest influences project in the Rocky Mountains of Colorado and one in the chaparral region of southern California, both involving forage cover in some degree, and both conducted by the Forest Service, have already been mentioned.

The influence of the forage cover is of such great significance in the control of erosion, either independently or in combination with brush or forest, that sooner or later it will have to be investigated in a thoroughgoing manner in other regions. Only through such investigations can some of the most fundamental relationships which underlie the maintenance of soil fertility and the prevention of disastrous erosion and stream damage be understood and systems of range management perfected which will insure satisfactory watershed protection.

2. FORAGE MANAGEMENT

The preceding sections deal exclusively with the fundamental science underlying the care and use of the forest range. Those which follow deal in part with the additional research necessary in the application of knowledge so gained. Application frequently requires research in order to be effective and in order also to improve wherever possible upon nature. Application problems will often be encountered which lead directly into fundamental investigations. Research of both classes will benefit if they can go forward simultaneously.

The point of approach in the discussion of forest range management is the range itself, or more properly the range forage as a by-product of the forest. Since the chief purpose in the use of forest land is obviously the growing of timber, it follows that the use of the forage cover must

be such that it will, if possible, aid and that in any case it will not interfere with this primary purpose.

In Relation to Timber Growing

One of the primary considerations, therefore, in all grazing research is to determine to what extent, if any, range utilization is interfering with the reproduction or growth of the timber and if possible to devise methods of handling livestock which will prevent such damage. Where range utilization can be made an aid to forest growth or at least conducted without injury, it is much to be desired from every standpoint. With truly intensive forest management many forest types will, at some stages at least, become so dense that the forage cannot persist, and grazing will automatically cease. In such cases investigations may be required to bring out the relative value of the forest and grazing use, particularly on the very poor timber sites or where the cost of exploiting the timber would be very high. Where there is a sharp, inherent conflict in land use between timber growing and grazing, careful study from a broad point of view will be necessary to determine which should be given preference. Under some conditions such as those of the western yellow pine forests of the Southwest and the hardwood forests of the Central States, the correlation of timber growing and grazing is a problem of great importance, the only satisfactory solution of which lies in research.

The Forest Service has determined the general relation of sheep and cattle grazing to yellow pine reproduction in the Southwest, in Idaho, and in certain other parts of the West; to aspen in central Utah; and of goat grazing to yellow pine, Douglas fir, piñon, and juniper in the Southwest. Investigations to reduce damage by changes in methods of grazing management have gone on simultaneously. Similar investigations to determine the possibility of combining cattle grazing and timber growing on the same area are now under way in the South by the Bureau of Animal Industry, the Mississippi Agricultural Experiment Station, and the Forest Service in cooperation. The Forest Service is also studying the damage to longleaf pine reproduction by hogs. A large amount of additional research of this kind will be essential as forest practice and range management increase in intensity.

In Relation to Erosion

In forage production just as in timber growing the soil is the basic resource. In order, therefore, to maintain soil fertility and to avoid stream damage and other evils, the prevention of erosion is a second prerequisite in all range management along with the prevention of damage to timber reproduction and growth. Fundamental investigations already described will have to be supplemented by a large number of general observations and less intensive checks and trials to determine local modifications. All forms of erosion will have to be taken into account, the sheet erosion characteristic of some soil formations, the gully erosion which occurs with others, and finally, the wind erosion which possibly has been recognized least of all. The problem has hardly been touched in most parts of the United States.

Systems of Forage Management

Systems of forage management parallel, for forage use and renewal, the silvicultural systems which utilize the mature timber crop and at the

same time perpetuate the forest. Range perpetuation with maximum grazing parallels forest perpetuation with maximum yields. While the primary emphasis is on the range, systems of range management and the underlying investigations cannot be divorced from the highest production of livestock of the best grades. A large amount of work to supplement the fundamental investigations of forest range and designed to improve upon unaided nature, and to meet localized conditions for different classes of stock, will be necessary in all forest regions where livestock grazing is possible.

The Forest Service has done and is still doing a good deal of work in this direction on the ranges of the western National Forests. The deferred and rotation system of grazing has, for example, been developed. This system involves the protection of each portion of the range one or more years in each rotation series until the more important palatable plants have matured, and in the case of the bunch grasses, seeded in addition. The practical application, including necessary adaptations, has been worked out in a general way for many of the western forests. Some preliminary work has been done on the best seasons for grazing, which includes the time or the stage of growth at which livestock may be admitted to the range without injury to the forage, methods of determining the date of range readiness, the effect of continued early use on the vigor and growth of the forage, and on criteria of the range conditions which indicate when livestock should be removed.

Detailed studies have also been made of handling sheep in coyote-proof pastures, and on the open National Forest range in a number of regions, to determine the most satisfactory size of band, method of herding, bedding, salting, watering, and lambing. The open herding and bedding-out system was devised and is now in practical application on many ranges. Similar studies have been made with goats in the Southwest. Cattle handling has also been studied in all parts of the West, particularly in obtaining satisfactory distribution on the range by salting and riding. Work has also been done looking towards the determination of the best distribution of watering places necessary for different classes of livestock under varying conditions of topography and forage in order evenly to utilize the range. Similar work has included the use and value of fences and other handling facilities. Still other experiments have attempted the control of poisonous plants by eradication and by special adaptations in methods of range management.

While a fair beginning has been made along this line, there is much investigative work still to be done. Practically every advance in fundamental knowledge will necessitate a corresponding series of investigations to work out local applications under different forage conditions for different classes of livestock. Likewise, advances in application in one region will show the necessity for further research in other regions before the advanced principle can be widely recommended.

The preceding systems of range management contemplate the perpetuation of the forage resource through natural methods of seeding. Reseeding is insured through adaptations in the handling of livestock. As in forest management there is a possibility that ranges may be perpetuated through artificial reseeding. This might be particularly true of strains of forage plants improved through plant breeding or where there is a possi-

bility of introducing exotics better than native species. Both the Forest Service and the Bureau of Plant Industry have done some work along this line. Intensive investigations in a few localities supplemented by seeding tests under many conditions in the West have shown that seeding range lands to cultivated species is practical only on mountain meadows and other areas of minor extent having favorable soil moisture and climatic conditions. A continuation of such work is justified on an experimental scale with important native species or as promising exotics are found and shown by more fundamental investigations to be suitable to American conditions and as improved strains are developed by plant breeding.

Forage and Fire Protection

Two aspects of the relation of fire to forage and grazing are important. The first, already referred to, is the effect of fire upon the forage itself or upon environmental factors which indirectly affect forage growth and succession. The second aspect is the possibility of reducing the forest fire menace by reducing through grazing the amount of the secondary vegetation on the ground. A general study of the second problem with some detailed work has been made by the Forest Service in the West. Although there are many contributing factors, fires spread more slowly and ordinarily do less damage where the area has been grazed. Under similar conditions on one Oregon National Forest, the average area burned for sheep allotments was 24 acres, cattle 114, and on practically ungrazed areas 391 acres. The importance and cost of forest fire control and the obvious relationship of the forage cover to it justify additional and more thorough investigation of the whole problem. This is merely another example of the intimate relationship between forage use and timber growing, and the investigations which are common to both. Fundamental investigations of the relationship between forage and fire will undoubtedly also have to be supplemented by more general research to determine the most effective application under varying local conditions.

Rodents and Game

The damage to range lands by rodents, such as prairie dogs, the Columbian ground squirrel, and kangaroo rats, is enormous, and definite plans for control have been under way for many years based upon considerable general and detailed investigation of the problem chiefly by the Biological Survey, but also by a number of State Agricultural Colleges. These control methods can undoubtedly be improved through further research. Little is known of the life histories and the environmental relationships of many rodents important from the forage standpoint, and it is therefore difficult to develop effective control measures.

The relationship between game and forage use should be referred to also as a phase of range management which must be taken into account in the handling of livestock.

3. ANIMAL HUSBANDRY

Investigations which fall under the general head of animal husbandry are more nearly in the field of agricultural than of forest science, and are touched upon only because the problems in forest range utilization differ

from those on agricultural lands, and even on non-forested ranges. The point of approach in these investigations is primarily the handling of the animals and not of the range, as under range management. Classes of investigation which should be considered here are, for example, the economic wintering of forest range stock, the development of breeds and types of livestock adapted to the range, diseases and parasites which affect range animals, losses from predatory animals, and most effective methods of protection. Work on predatory animals is being conducted mainly by the Biological Survey and must be continued for some time to come in order to secure the desired results. On livestock breeding and diseases an immense amount of work has been done for eastern conditions by the Bureau of Animal Industry and the agricultural colleges. Not nearly so much has been attempted in the South and West. The field to be covered is still very large.

4. CARRYING CAPACITY

The determination of carrying capacity involves the classification of ranges and estimates of the numbers of livestock which each class can and should carry in the light of the requirements for timber growing, soil and watershed protection, maintenance of the forage, and the best development of livestock. It assumes intensive methods of range management and livestock regulation. It should in one sense be a final expression of all the fundamental and applied research which has been outlined. It contains a large research element, supplemented, to be sure, by equally important elements of application.

Carrying capacity is usually expressed in surface acreage. On National Forests the value of surface acres varies so widely that the forage acre, which is the surface acre times the density of vegetation in percentage of total ground cover times its average palatability expressed in percentage, has been developed to give a more uniform estimate of carrying capacity. There are so many influencing factors, however, that even forage acreages cannot be used without adjustment. On nonforest areas the Bureaus of Plant and Animal Industry and a number of State agricultural colleges have been investigating carrying capacity. The Texas Agricultural Experiment Station has developed a more uniform carrying capacity basis than the surface acre, but so far it has not been tried out on an extensive scale.

While the Forest Service has investigated carrying capacity in connection with the handling of the western National Forest ranges, the satisfactory solution of the problem even there is still for the most part ahead. Comparatively little has been attempted along these lines for forested areas in other parts of the United States. All parts of the country must be covered if one of the most important by-products of the forest is to be fully utilized.

5. OUTSTANDING PROGRESS AND PROBLEMS

Research in forest range management has made by far the greatest progress in the development of improved systems of range management, in determining the carrying capacity of different classes of range in terms of different kinds of livestock, in ascertaining the food values of very large numbers of forage plants, and in the classification and descrip-

tion of such plants. It has also determined a few of the most important principles underlying forest range management and the methods of handling livestock on forest ranges.

Future work requiring most emphasis is first the much more comprehensive and fundamental determination of the nutrition value and palatability of each of the plants which make up the forest range; a second class includes the life histories and the ecological relationships of all forage plants and associations; a third the ecological and physiological reaction of all plants to grazing by livestock. The results from work on these three groups of fundamental investigations will be an invaluable guide in all applied research and in all forest range management.

In applied research the outstanding problems are the further perfection of systems of range management and a more exact determination of carrying capacity, including the exact effect of the many factors which influence it, and the perfection of livestock management on the range. All research, however, whether fundamental or applied, must have constantly in the background the primary requisites of timber growing and the preservation of the soil conditions which are essential not only to the growing of the maximum timber crops but also to the maximum crops of the forage itself.

WILD LIFE AND RECREATION

1. WILD LIFE

Such a large proportion of past research on the wild life of the forest has been confined to taxonomic relationships, and such a large proportion of past efforts to administer these resources has been largely devoid of foundation in scientific fact, that the outstanding problem of the present generation is to focus research on the place of each species in the ecology of its environment. This should be accompanied by closely related research on life habits. From the facts thus gained can be built a really effective technology of conservation and control. Improved administration will inevitably follow but cannot far precede the discovery of the necessary facts through research.

The present lack of ecological knowledge as well as that of life histories is forcibly illustrated by the Michigan grayling. This very valuable game fish has disappeared with almost dramatic suddenness. No one knows why, but it is pretty certain that the cause lies in some environmental change rather than in any direct damage by man or by any natural enemy. It is probable that there is some connection between its disappearance and the removal of the forests which once covered the banks and watersheds of its native streams. A recent discovery in the study of muskellunge lends color to the supposition that the grayling succumbed to some environmental change. For years attempts to rear the muskellunge in hatcheries for restocking have been unsuccessful. Research of the University of Illinois has now shown that the muskellunge cannot lay eggs except within certain very narrow temperature limits of ½° F., and that if the proper water temperatures do not exist at the proper season, the eggs are reabsorbed and no reproduction takes place. Changes in forest cover which are very probably reflected in changes in water temperatures

of the lakes and streams in which the muskellunge occurs, may well be one of the chief reasons why, in many localities, the muskellunge has been decreasing more rapidly than other factors would appear to warrant.

In both grayling and muskellunge we have a valuable resource of forest land, injured apparently by environmental factors far beyond our present knowledge, but, if the requisite knowledge existed, not necessarily beyond our control. In both cases remedial measures are probably futile pending the completion of the necessary research.

Research problems of the wild life of the forest involve more than game, fish, and fur. The relation of the snowshoe rabbit to white pine has been already cited. Rodents like squirrels and mice hoard and consume the seeds of forest trees, and thus play an important part in forest reproduction. In some parts of the western yellow pine territory a large part of the reproduction appears to come from seeds planted by rodents. One mouse has been known to eat 300 and one chipmunk 600 seeds of Douglas fir in a single day. Burrowing rodents often play a part in the working of forest soils. Pocket gophers cut off the roots of trees. Birds carry tree diseases such as the chestnut blight, and consume seeds; but they also plant seeds, and by preying upon injurious insects prevent or shorten insect epidemics. Squirrels defoliate and porcupines strip the bark of important trees. In Arizona porcupines on an experimental area killed 50 per cent of the pine seedlings and saplings under 5 feet high within a three-year period, and under conditions in which it is difficult at best to obtain satisfactory reproduction. Pack rats in California have been known to destroy a forest plantation within ten days after the seedlings were put into the ground.

Nor are the problems of wild life research confined to cases involving a direct relation to timber. Prairie dogs, ground squirrels, gophers, and kangaroo rats consume in enormous quantities the kinds of forage plants which are most nutritious for livestock. Over considerable areas prairie dogs, for example, have been known to consume 80 per cent of the available forage of the range.

Predatory animals, such as wolves and mountain lions, often destroy livestock to the extent of affecting the value of forest range. One national forest, for example, in one year lost approximately 5,800 sheep from coyotes and other predatory animals.

Wild life research is often confronted simultaneously by series of interrelated problems of biological balance covering nearly the whole range of biology. Thus the parasites which cause extreme fluctuations in the abundance of ruffed grouse in the Lake States may involve the snowshoe rabbit as an intermediate host. This in turn involves the damage these rabbits inflict upon white pine reproduction, and the effect of predatory animals on the fluctuations in abundance of rabbits. Predatory animal control undoubtedly affects the deer supply, which may depend on the maintenance of the white cedar swamps that provide the deer with winter yarding grounds and feed. Here a single chain of phenomena appears to extend from one end to the other of the animal kingdom, and each phenomenon is tied in directly with the forest and its welfare.

The need for research in the ecology and the life histories of wild life has of course not escaped the attention of naturalists and research institutions, and an increasing amount of effort is being directed toward work-

ing out the life histories and the ecological relations underlying conservation and control work. Not only government agencies like the Biological Survey but State institutions like the Roosevelt Wild Life Experiment Station are making good progress in this kind of work. The hiatus between administration and science, however, is not decreasing as rapidly as the urgent problems are accumulating. Only a great impetus to research can adequately protect the public interests at stake.

If wild life for food or fur or recreation is to be a by-product of the forest, as it should be, and in fact as the maintenance of the desired biological balance in some instances compels it to be, there is great advantage in a sustained output. It should be definitely known what numbers can be maintained and what numbers can be removed each year without reducing breeding stocks below the point of safety. When these things are known, limitations may have to be placed not only on the seasons, age, sex, but also the numbers that can be removed, all based on a thorough understanding of the life histories and ecological relationships of the animal concerned. The basis will have to be far more substantial than that which underlies existing game laws in the United States, which almost without exception have only very unsatisfactory empirical foundations.

Where the forest requires protection from any kind of wild life, special measures for poisoning or other forms of control will be necessary, depending upon the ecological relationships of the animal and its life habits, such as preferences for food. For example, a thoroughgoing attempt to poison seed-eating rodents in Montana in order to obtain forest reproduction failed because the poisoned grain used was put out in the hoarding season and consequently was stored rather than eaten. Most research looking towards protection has been conducted on those animals which consume forage or prey on livestock, and this primarily by the Biological Survey, although a number of western agricultural colleges have contributed. The Biological Survey has done considerable work in cooperation with the Forest Service on porcupines and various rodents which destroy seedlings or young trees.

Finally, all of these inquiries into ecological relationships, life histories, protection, and game management must be undertaken not as distinct studies which are final objectives in themselves, but rather as parts of a much broader system of forest management, which includes timber primarily, forage for the grazing of livestock as an important product, wild life and recreation as others, and forest influences on erosion and streamflow as still another. All of these products must be regarded as different forms of the service which the forest land can render, and each must receive its proper emphasis. All research on wild life must therefore have this balance constantly in the background.

2. RECREATION

The greatest contribution which research can make to recreation is the maintenance of wild life in forests and the maintenance of the forest itself. Probably the most important additional contribution will be to furnish the facts as to the relative value of the economic and social service which timber growing, recreation, and other uses can render, so that on

the basis of these facts the owner of the land can make a more intelligent decision on the policy which should govern his plan of management. This is essentially a problem of land economics.

UTILIZATION OF WOOD AND OTHER FOREST PRODUCTS

Forest research cannot stop with the fundamental and applied science of the growing tree and the forest.

Wood, the chief product, is after all only a raw material, a resource in the true sense of the word, and like most biological products, complex and exceedingly variable within the limits of a single species and infinitely more so between species. The characteristics and properties of wood are the resultant in part of the inherent or distinctive life processes of the individual tree species. This, for example, explains the constant differences between the woods of red oak and white pine grown side by side under practically identical ecological conditions. But the characteristics and properties are in part also the resultant of differences in growing conditions which cause marked variation in strength and many other properties even within the same species. The Douglas fir of the humid Pacific Coast and that of the semi-arid Central Rocky Mountains are as distinctive in woods as are the climatic and other conditions which influence their growth. The same is true of species of some oaks and ashes, the range of which extends from the hot lower Mississippi bottoms to the well-drained soils of the cooler northern States.

The wood product must be harvested and manufactured. It is then put to a large number of uses, all variable in their conditions and requirements. It must meet the competition of a large number of materials, which is growing in intensity from year to year. The use of many of these competing materials is based upon research which shows both their properties and their suitability for the particular uses which are made of them.

The best use of wood depends, therefore, upon the right balance between the properties and behavior of wood on the one hand and the requirements of use on the other. The determination of such balances for all uses and all species of wood is one of the main functions of forest products research. A second important function is the elimination of unnecessary waste in all stages of manufacture and subsequent use.

So far in the United States forest products research has had a greater popular appeal than any other class of forest research and this has resulted in larger appropriations. Greater progress may be reflected in a somewhat more detailed discussion of forest products research than of other classes.

The characteristics and properties of wood may be divided into two broad classes, physical and chemical, which are distinct in their extremes, but which merge, as the fact that physical chemistry must be employed in the attack on some wood problems indicates.

1. WOOD AS A PHYSICAL SUBSTANCE

Wood as a physical substance or material is characterized by diversified groups of properties, among which are structure, various strength proper-

ties, specific gravity, heat conductivity and other heat relationships, penetrability by and transmission of water and other liquids and other moisture relationships, swelling, shrinking, and checking, working properties as indicated in part by the ease of working with tools, resonance, and electrical conductivity.

PHYSICAL PROPERTIES AND GROWING CONDITIONS

The relation between conditions of growth, the inherent physiological processes of different tree species, and the physical characteristics and properties of wood, indicate the necessity for correlated effort between forest ecologists, physiologists, and biochemists who study the formation of wood in the living tree, and the physicists who inquire into the nature of and the ultimate why of the physical properties of wood. Questions of similar relationships between chemical properties, conditions of growth, and tree physiology may also arise, which will also require cooperative research.

Some of the important phases of the physical property and ecological relationships are brought together for clarity and emphasis even though reference will necessarily again be made to some of them.

A beginning has been made by the Forest Service on the relationship between growth conditions and strength, and work is still under way. Specific gravity as an indication of strength has in the case of ash and hickory been checked against growth conditions as represented by the changes in the width of the annual growth layer. It has been found for these two species that the initial strength of the wood in the center of the tree may at least be maintained in the outer rings when natural conditions or forest management is of such a character that the growth rate is maintained or increased. Where, however, unfavorable conditions slow down the initial growth, the strength suffers correspondingly. Practically all of this important field, however, lies ahead.

It is already well understood that conditions of growth have a very important effect upon the seasoning characteristics of the oaks. Southern swamp-grown oak is in general much more difficult to season than wood of the same species from northern highlands. Not only is there a larger amount of moisture in the living tree, but also such properties as plasticity and shrinkage and the laws governing the relationships between shrinkage and drying seem to be materially different. In short, there is undoubtedly a close relation between the physical properties of wood, the physiological activities of the tree which produce the wood, and the conditions under which the tree grows. If our forest management and the utilization of the product are to be effective, basic knowledge must eventually be obtained on the effect of such conditions as altitude and latitude, soil variation, excess moisture in swamps or from floods, and the competitive forest conditions in general upon the physiology of the tree and upon the properties and the behavior of the wood.

The relation between growing conditions and both the gross and minute structure of wood is very direct. The porosity of wood, for example, is modified by growing conditions. Second-growth wood in general differs from old-growth material in many particulars, including structure. It has been produced under entirely different growing conditions.

What can be done in forest practice to influence conditions of growth

is definitely limited, but the small amount of work so far attempted unquestionably indicates the practicability under some conditions of measures which will insure a better product. As a minimum it may be of the utmost value to know, as in the case of the oak, that specified growing conditions will give rise to wood of known characteristics or properties. Users can take this into account in their purchases even though it is not always feasible for the forester to modify the conditions of growth.

THE STRUCTURE OF WOOD

Wood is largely a rather complex cellular structure with considerable variation as between several different classes of cells. Most woods contain also gums, starches, sugars, tannins, coloring materials, and other so-called extractives which are not an essential part of the structure itself.

While knowledge of only the larger and more obvious variations and combinations in cellular structure is ordinarily necessary for the recognition of different kinds of wood, there are undoubtedly fundamental differences in the finer details of structure, as yet largely unknown, in the understanding of which may lie the final solution of many forest products problems. In short, some relation undoubtedly exists between the structure of woods and their other physical characteristics and properties. That many conifers are not as desirable for smooth surfaces as the hardwoods because their grain is apt to raise, and that certain second-growth hardwoods are preferable to virgin timber where a tough wood is desired, probably reflect differences in the relative size and arrangement of the cells and the amount and kind of material in the cell walls. Nevertheless only a few of the relations between the structure of wood and its other properties have as yet been worked out.

Structure and Identification

The characteristic features of the structure as influenced by genera and species must be ascertained and described for purposes of identification and subsequent research in wood utilization wholly aside from any similar need for understanding wood formation as a resultant of the life processes of the tree. The work in forest products on structure begins theoretically with wood as a completed product where investigations on tree growth leave off. Means of identifying the genera of the more important woods have been known for a long time and in many instances have extended to species. A large amount of more recent work by Yale and other forest schools and by the Forest Service has supplied more extensive and systematic distinctions between species, their typical cellular structure, and the extent of the variations from the typical, but this work is far from complete.

Structure and Strength

The relation of the width of the annual rings and percentage of summer wood to strength have been studied by the Forest Service in the southern pines, Douglas fir, and several other species sufficiently to show that in general the width of the annual rings is not a reliable indication of strength. The percentage of summer wood shows a more definite relation, particularly in the southern pines, but is not so reliable as specific gravity for estimating strength. Evidently strength is determined pri-

marily by some less obvious structural features which need investigation. The effect on strength of such structural defects as knots, cross-grain, and compression wood is known and will be discussed later.

Why some pieces of apparently sound wood are brash is being studied in the Forest Service to see if brashness can be traced to intrinsic characteristics of the wood resulting from growth conditions or to subsequent changes in it. It has been found that in oak brashness in some cases evidently is due to scarcity of wood fibers, and seems to be accompanied by an unusually high percentage of crystals and mineral matter, while in spruce, for example, it has been found due to wind stresses or rough handling in logging. The influence on strength of variations in the cellular structure will when known be helpful in more concrete estimates of strength than are now possible, and perhaps also in the regulation of forest management to avoid the production of weak timber.

Structure and Diffusion of Liquids

Investigations of the penetration of wood by liquids have been carried on by the Forest Service intermittently for some years. As might be anticipated, rather marked difference has been shown between species of woods with different structure and between spring wood and summer wood of different and even of the same species. Spring and summer wood of the same species have been found to behave differently with different liquids. Penetration studies have also been carried on by Harvard University. But a great deal more needs to be known about the purely structural characteristics which influence the passage of liquids through the cell walls before marked improvements may be expected in such processes as wood preservation, which consists merely in the injection into the wood of liquids toxic to fungi, insects, and marine borers. Upon an understanding of the structural characteristics which influence moisture diffusion through the cells depends in part also the regulation of seasoning, or the removal of moisture, one of the most important processes in the handling of wood. Moisture diffusion depends probably not so much on the size of pores and other semi-microscopic features as on the finer details of the cell structure, of which at present very little is known. Moisture transmission in wood is closely associated with sap ascent and the distribution of different solutions in living trees, and knowledge of either will probably help to an understanding of the other.

Structure and Shrinkage

Further evidence gathered by the Forest Service in support of the theory that wood fibers have a fibrillar spiral structure has led to a hypothesis that variations in longitudinal shrinkage are due to differences in the average inclination of the constituent spiral strands or fibrils. This hypothesis helps to explain some puzzling problems, but its relation to transverse shrinkage still awaits further explanation. To what extent chemical composition is a factor in shrinkage is uncertain with our present knowledge, particularly of the cellular nature of wood. It seems, however, that there must be some structural differences which account for a range of shrinkage in volume from 7 to 19 per cent for important woods such as white cedar and hickory. Until the mechanism of shrinkage is

better understood, attempts to solve the many shrinkage problems such as checking, warping, case hardening, and honeycombing, remain more or less handicapped. A little work on the relation of structure to shrinkage has been done mainly in the Forest Service, but practically the entire problem is ahead.

Structure and Working Properties

The different ways in which various woods work under tools is an expression of differences in obscure properties which have not been studied at all. Why do some woods like white pine surface easily while others like elm commonly rough up? Why does the grain raise in some woods like cypress and not in others like cedar? Why do some woods dull tools more than others of no greater density? An understanding of the real nature of these properties probably depends in part upon knowledge of the structure.

Structure and Resin Formation

Microscopic studies of structure by the Forest Service and microchemical tests in cooperation with the Boyce Thompson Institute have shown the excessive reduction in wood and resiniferous tissue formation resulting from overcupping small longleaf and slash pine trees in naval stores operations. The remarkable responsive power of young trees and their high potential productivity under proper working has been shown by a study of the wound wood produced after turpentining. The possibility of building up these tissues in advance of regular working is under test. The study of high and low yielding trees is also in progress. Some information on structural characteristics as indicators of vigor and producing power have been obtained. This work should be continued and enlarged. It ties in closely with basic investigations of the physiological processes of formation, storage, and diffusion of oleoresins by the pines and with investigations of the ecological conditions which influence the process.

Structure and Pulping Properties

How the pulping qualities of wood are affected by its structure in the aggregate and how the paper-making qualities are affected by the characteristics of the individual fibers, is an almost virgin field, which is none the less fundamental because it aims at the solution of practical problems. The extent to which the cementing layers between the fibers can be removed without materially affecting the fibers themselves in cooking pulp and how the roughening of the surfaces of the fibers during preparation and their twisting in drying affect the quality of paper, are important things to know. The results of research on such problems are basic to improvements in present paper-making methods, but practically nothing has been done.

Minute Structure in General

In general, fundamental research on the nature and the minute structure of cell walls, how the cells are built up, how the different chemical compounds of which wood is composed are distributed in the cell wall, and how the tracheid tissue which is characteristic of conifers compares in these respects with the fiber tissue of the hardwoods, should be carried

on independently of any specific practical application, because it bears on nearly all problems pertaining to efficient wood utilization. The more closely it can be related to the life processes of the tree and finally to conditions of growth the more valuable it will be. Only a bare beginning on work of this character has been made.

THE STRENGTH OF WOOD

Closely related to the structure of wood and equally important in many forms of use is strength. In the neighborhood of one-fifth of the timber utilized in the United States each year is used in ways in which strength is a primary consideration. Knowledge of strength is involved in the design of practically all articles made of wood.

Laws of Mechanics and Standard Tests

A limited number of fundamental or general laws of mechanics, such as the theory of the moment of forces, which have been known for many years, are of great importance in the testing and use of wood. These laws serve as a basis for the derivation of mathematical formulas which express the theoretical effect of the application of force on matter. The formulas make possible the computation of the intensity and the distribution of the stresses set up in a material by outside forces. They also make possible the comparison of the strength of materials on a unit basis, as, for example, pounds per square inch.

One of the first necessities in investigating the fundamental strength properties of such a nonhomogeneous and variable material as wood is to ascertain whether the formulas commonly used apply, or whether correction factors or new formulas are necessary. It is also necessary through a series of standardized tests to obtain the basic data which after computation with the proper formulas take the form of tables showing unit stresses on a comparable basis.

Tests and the preparation of tables have been under way on a large scale for many years in the Forest Service, and checks of formulas to a lesser extent. In order to obtain data on wood with the disturbing influences of knots, checks, and other defects eliminated, small clear pieces of uniform size have been used. The standard tests made have included static bending, impact bending, compression parallel to the grain, compression perpendicular to the grain, shearing, tension, cleavage, and hardness. It will probably be necessary in the case of some woods and for special purposes to add tests of torsion, abrasion, and possibly others, which so far have received relatively little attention.

Strength by Species

Standardized tests made by the Forest Service to determine the properties of about 160 of the most important American species now aggregate about 200,000 and more are under way. The Canadian government under a similar program of standardized tests has worked on some 60 Canadian species which are also native to the United States. The tables which have been prepared from these tests are fundamental to all other scientific work on the strength factors of wood and equally to the use of wood where strength is required.

The remaining American species of relatively minor importance should be tested. The tests which to date are almost entirely on virgin timber

should be extended to second-growth material, which may or may not be identical because it has in many cases grown under entirely different conditions. A vast amount of work remains, therefore, on our native species alone. Since South American hardwoods may help to bridge the gap between the exhaustion of our virgin supplies and the maturity of new forests, supplemental tests on species suitable for import will undoubtedly be needed. Finally, the why of variations in strength can be determined only through the investigations of wood structure already outlined and possibly also of the physiological processes under which the wood has formed, and of its chemical properties.

Tests by species are also involved in practically all of the strength relationships.

Strength and Density

Only a few tests of wood were required to show the existence of a close relationship between density or specific gravity and some at least of the strength properties. A good deal of systematic work has therefore been done by the Forest Service along this line and is still under way primarily to work out the relationship between density on the one hand, and strength in bending, compression parallel to the grain, compression perpendicular to the grain, and hardness on the other. The results of the standardized tests previously mentioned form the basis for this analysis. It has been found, for example, that the relation of bending strength to weight of dry wood or specific gravity is represented by a nearly straight line. While for most species the general averages obtained fall close to the line, there are some significant variations. In some of the important properties the oaks as a group fall considerably below and the hickories somewhat above what might be expected from the density of their woods. Every species so far studied has been found to be above what would be expected in some properties and below in others. It is necessary, therefore, to check all new species tested against the general laws to determine conformity or otherwise. In deviation from the general law are sometimes found the peculiar properties which give woods their greatest value for specific purposes, as, for instance, the toughness of hickory. Another great value of these density-strength relationships is the possibility of using specific gravity, which can be easily ascertained, as a basis for grading and for the selection of material for uses where high strength is required.

Strength and Moisture

Similarly the Forest Service also found very early in the strength tests of wood that wide variations coincided with difference in moisture content. Water is absorbed in cell walls, but occurs also in the cell cavities. It has been found that no change occurs in the strength of green or wet wood until the moisture in the cell cavities has disappeared and the drying of the cell walls begins at what is called the fiber saturation point. Thereafter most strength properties continue to increase as the moisture content decreases.

Tests on a number of species covering a considerable range with respect to specific gravity and structure have shown that the relation between moisture content and the various strength properties is expressed by an exponential type of equation. Further research is needed to deter-

mine whether, as appears to be the case, the type equation is applicable to all species and to find the fiber saturation point for additional species.

The tests to date indicate a much wider variation with species (21-33 per cent moisture at fiber saturation point) than would have been expected, and that the moisture content at which changes in strength begin varies with the property considered. Furthermore, fiber saturation points as determined from strength tests and shrinkage measurements do not agree. The cause and significance of these facts is a subject for further investigation.

Information of this character is needed for all species where specialized use requires exceptional strength. Possibly also the investigations should be broadened to include such other strength properties as compression across the grain. Moisture influences the strength of wood so greatly that Forest Service tables of unit stresses have shown the moisture condition of the material at the time tested. Tables are now being computed to a uniform moisture percentage. Work on moisture strength relationship in general is also being carried forward.

Strength and Grain

That spiral grain, which is the result of growth in the tree, and cross grain, which results from the manner of cutting, affect the strength of wood is obvious. The point at which either might become important, however, was uncertain until extensive tests by the Forest Service established the relation between angle of grain and several important strength properties. Knowledge of this sort is vital in the selection of wood for such purposes as ladders, pike poles, and airplane construction where it is necessary to secure the greatest strength from the lightest possible weight.

Strength and Position in the Tree

For the standard material tests on small-sized pieces records have been kept of the location from which they were cut in the tree, including distance from the pith and height above ground. The analysis shows that the variation in strength with position in cross-section is the result of a number of factors. No general rule, therefore, can be formulated to cover all cases. In conifers the variation in strength with position in height is in general a lowering in strength with increase in distance above the ground, and in most species the toughest and most shock-resistant material is found in the butt cut.

Other Strength Properties

Other important strength problems, which are almost as fundamental as those discussed, need attention—the influence of defects on the strength of structural timbers, the development of special formulas for columns and for beams of different cross sections, and the forces exerted by wood in swelling. All of these problems have such direct bearing on application that they are discussed under Design.

OTHER PHYSICAL PROPERTIES OF WOOD

Specific Gravity

Structure and strength, important though they are, constitute only a part of the physical properties of wood. Specific gravity is one of the

most useful of the other properties. It can be determined with relative ease and is of very great value, for instance, in the approximate determination of other properties such as strength, the testing for which would involve a very material amount of work. In practically all of the 600,000 or so standard tests of small clear pieces, which the Forest Service has thus far made in all its various projects, a determination of specific gravity has been included. Presumably something of this same character has been done by other institutions which have made tests. An intensive investigation conducted by the Forest Service has further shown the specific gravity of the actual wood material to be constant, irrespective of species. Since there is a close relationship between specific gravity and various physical properties it is essential that proper consideration be given to specific gravity in all of the investigations of these properties. The need for special investigations upon specific gravity as an isolated property is not anticipated.

Heat Relationships

It is well known that wood conducts heat slowly and that this is the property which makes it particularly desirable for such uses as building material, furniture, and handles. Tests designed to determine the rate of heat transmission have been made by the Forest Service and have shown, for example, that it requires from five to eight hours to heat through to the center an eight inch timber in saturated steam at 20-40 pounds pressure. They have shown that the heat conductivity of wood along the fibers is from two to three times as great as that transversely. Since vaporization is dependent upon heat supply the rate of drying of the interior of dense woods is greatly influenced by the rate of heat conduction through the surface. Heat treatment reduces the hygroscopicity and consequently the shrinkage and swelling. Exposure for several hours to 400° F. reduces hygroscopicity nearly one-half.

A rather exhaustive series of investigations have shown the specific heat of all the woods tested to be approximately .327. Knowledge of the latter character is of value in many industrial processes such as the distillation of wood, its preservative treatment, and kiln drying. It has been found that high temperatures cause brittleness and loss in strength. Heat in combination with moisture makes important changes in the plasticity of the wood substance. In a general way we know what happens under a limited range of conditions and for a very limited number of liquids. We ought, however, in connection with a study of heat and the conductivity of heat by wood to know much more fully just what changes it makes in the wood substance and why. Knowledge of this sort would have a long series of important applications in all of the processes above listed and possibly many more. It is apparent that the study of heat relationships can not be separated from those of water and other liquids.

Moisture Relationships

The effect of moisture on the properties and the manner in which moisture moves through wood are factors of basic importance in practically all utilization problems. Among the properties affected by moisture are shrinkage, plasticity, strength and stiffness, hygroscopicity, "setting," heat and electrical conductivity, color, stain, durability, and collapse. Very little

knowledge has been obtained on the ultimate nature or causes of the moisture relationship from the many experiments conducted.

A wide variety of studies has been made by the Forest Service and data obtained upon the relationship between the moisture content of wood and the humidity of the surrounding air, and upon the rate of absorption of moisture by wood both from the atmosphere and when submerged. An extensive series of tests to determine the laws underlying the transfusion of moisture through wood and the effect of temperature, humidity, and air circulation as isolated factors upon the drying rate and the properties of wood has been under way for a number of years.

A great many measurements have been made upon the shrinkage of wood as it dries and upon its swelling when moisture is reabsorbed. It has been found, for example, that hickory among our native species shows about the maximum of shrinkage, something like 19 per cent of the green volume of the wood; whereas white pine is nearly the minimum, with about 8 per cent. The effect of different methods of drying upon the amount of shinkage has been studied. A great deal of information has been obtained upon the manner in which various drying defects such as set and collapse occur and how they may be avoided or removed. We ought, however, to find out just what changes occur in the physical nature of the wood when it sets, because this would give the clue to some of the most perplexing problems in kiln drying, which now can be handled only empirically. Several series of experiments are under way to determine the exact manner in which moisture moves through wood, a baffling problem of great importance.

Other Liquids

Water, however, is only one of the liquids with which we are concerned. The reaction of wood to oils such as may be used in preservative treatments, to various acids and alkalies which are used in chemical pulping processes, to the bleaching agents which are used in the bleaching of pulps, to the paints which are used in the protection of wood, may all be radically different. Uniformity in chemical pulping, for example, requires the uniform distribution of chemicals throughout the wood. Basic to a control of this distribution is a knowledge of the rate of penetration into the wood, especially as affected by temperature, pressure, time, and the nature of the various chemicals. The isolation and study of these factors would make possible higher yields of pulp of greater uniformity and also economize operating time. In spite of the fact that a great deal of information upon these various subjects has been accumulated, the work to date represents only a start upon what must be done before a comprehensive knowledge of the properties and the laws governing their changes may be had. The great variability in wood and in its behavior makes it very difficult to work out laws which can be applied to more than a very limited extent.

Electrical Conductivity

The Forest Service and the Bureau of Standards have made a few determinations upon the electrical conductivity of wood, and the Bureau of Standards has independently made various tests of the electrical properties of wood under certain specific conditions such, for instance, as those found in storage batteries. The various commercial electrical

research laboratories have also done some work upon the electrical resistance of wood at different moisture contents.

Resonance

The various piano companies have done some experimental work upon the resonance of wood. Little is known, however, beyond the fact that this property is apparently based on a combination of uniform structure, stiffness, and the absence of large rays or pores, and this is little more than inference.

Working Properties

The working properties of wood and the problems they present have already been discussed in connection with structure, which seems to be in considerable part, at least, responsible for them. There may also be factors in the physical nature of the wood other than the structure, and much more obscure in the light of our present knowledge, which have an important significance in these working properties and which accordingly we ought to know more about. The lumber trade recognizes vaguely, and with much uncertainty and radical differences of opinion, obscure differences between woods, and even woods of the same species from different parts of their ranges—for example, oak. What we need first of all is a definition of the so-called working properties, and second, a determination of what they are, what causes them, how they differ as between species and within the same species. These problems ought to be worked out regardless of whether they involve questions of structure alone or of other physical or even chemical properties.

Altogether this rather miscellaneous group of other physical properties is one of the most important in the whole field of forest products research. It involves without exception and in an exceedingly important way every use which is made of wood. It underlies the efficiency of many of the most important processes used in the manufacture of wood. Although a large amount of work has been done, it constitutes only a beginning toward the knowledge which we should have to manufacture and use wood efficiently.

THE MODIFICATION OF PHYSICAL PROPERTIES

There are many cases in which utilization would be much more effective if it were possible to modify some of the properties of the wood, such for instance, as the swelling and shrinking which accompany changes in moisture content with changes in atmospheric humidity. The development of methods for accomplishing this depends upon a thorough knowledge of the properties which have already been discussed and possibly of still others which we do not yet even appreciate.

Although but little success has so far attended efforts to increase the strength of wood by special treatment, such changes may not be entirely unfeasible. Wood has been "collapsed" to increase density and change properties, but some method which will increase strength and stiffness without radically changing weight offers an opening for research. Success would eliminate great industrial wastes from the rejection of material.

It is common knowledge that the strength of wood may be modified temporarily by steaming. While in a semi-plastic stage, due probably in part to moisture and in part to heat, wood may be bent much more easily.

Present losses of the highest grade material in steam bending are very high, however, and the limited investigative work which has been attempted in the Forest Service should be greatly expanded in order to furnish a scientific basis for reducing waste from this source.

It should also be possible to modify other physical properties to a certain degree. Various experiments have been made to determine the effect of impregnation treatments with oils, sugars, etc., and of heat treatments of different kinds upon the hygroscopicity, shrinkage, and allied properties of wood, but as yet without very striking results. The ability of wood to stay in place is closely related to hygroscopicity. If this extremely important property could be improved, it would be a very important step in effective utilization. The modification of the hygroscopicity of wood might have a material effect upon the seasoning and the shrinkage properties and might lead to important developments in seasoning.

Still other important properties, the modification of which might assist materially in more effective utilization, are resonance, susceptibility to polish, resistance to wear, hardening, softening, ease of shaping with hand and machine tools, and the working properties in general. Pencil manufacturers have attempted with indifferent success to soften woods and make them more susceptible to easy cutting for use in pencil making.

2. THE CONVERSION AND USE OF WOOD AS A PHYSICAL SUBSTANCE

In the light of the fundamental program outlined, it is possible to consider more intelligently the research problems which center around the logging, manufacture, seasoning, design, and use of wood as a physical substance—for example, in lumber and structural timbers, in general building and construction, and in boxes. These problems will necessitate supplemental investigations to insure the correct adaptation of fundamental laws to industrial practice, to bridge over, for instance, the gap between tests on small clear pieces of wood and the much larger structural timbers, telephone poles, and mining timbers, which invariably contain defects. Supplemental research aimed directly at the reduction in waste, which now aggregates two-thirds of the entire volume of the timber cut in the forest will also be required, although all basic research bears upon waste directly or indirectly.

MANUFACTURE

Lumber

Lumber manufacture alone is responsible for one-third of the drain on our forests. A large proportion of all lumber is remanufactured before final use. It may be in industries which turn out such products as furniture, vehicles, and agricultural implements, or it may be in a diversified group of uses which can be classed under the general term of building and construction. Waste is very large because of the extent to which the tree must be cut and recut before the wood is put to final use.

There are three important methods of attack on the lumber waste problem. The first studies the processes of logging, sawmill operations, and the diversified remanufacture above indicated. These investigations

should for one thing improve processes and hence reduce wastes, and may also reduce operating costs. But their chief purpose should be to ascertain the character of wastes as to quality, form, quantity, and distribution, and to analyze their causes. Obviously the entire approach must be constructive with the primary idea of finding ways and means to improve utilization.

The second method of attack is to find places for the utilization of waste. An equally comprehensive study of the requirements of all the industries which use lumber is necessary, therefore, to determine sizes, qualities, properties, and quantities. The second method of attack should supplement the first and afford complete knowledge of the opportunities to use the waste discovered in the first set of investigations and which can not be saved directly by better methods of manufacture.

The third method of attack, referred to here only for completeness, should be the standardization of lumber specifications or grades to get uniformity between species and regions and thus afford the maximum aid to utilization through country-wide standards.

In lumber production the waste of material, necessary and otherwise, begins in the woods. It occurs in unnecessary breakage of trees in logging, in the poor division of the felled tree into log lengths, and in such other ways as the leaving of small and poor logs in the woods. It continues in the sawmill. Wide saw kerf has resulted from the effort to obtain high-speed saws, and more economical sawing is of first importance. Here the development of sawing equipment which will reduce saw kerfs without undue sacrifice of speed is badly needed. This is especially true of small portable sawmills where thoroughly efficient portable band saw equipment would result in vast economies in lumber manufacture.

A large proportion of the contents of the log is lost in slabs and edgings because possible returns from their manufacture into the small cuttings that many industries use are unknown. Present day machinery is designed for full length lumber or strip material. The development of machinery to handle small pieces would aid in the use of large quantities of waste.

A large amount of waste occurs in the forest because of the non-use or partial use only of some less popular species, as for instance, the white fir common to many western forests. Here facts regarding the physical and chemical properties of the species and their suitability for specific uses, as well as the ways and means of overcoming serious difficulties in conversion and use, are needed to remove unwarranted prejudice and to bring these little-used species into the markets in their proper place.

Scattered, fragmentary research on the problem of logging and lumber manufacture looking primarily toward better utilization has been under way for many years. Individual concerns have made investigations of their own operations. Associations have attempted solutions. Here and there a State has studied some phase of the problem. The Forest Service has conducted in different regions partial studies of waste in the woods and of more efficient milling practice. All these things have helped, and the amount of effort is gradually increasing. Economic pressure alone has made for progress. What the situation demands, however, is a country-wide study which will take up the problem in all forest regions from the standing tree to the delivered manufactured product. Probably no one

agency can satisfactorily attack this problem alone. Its very nature necessitates cooperation by many agencies, private and public. Its size fully justifies national effort. Following such an initial survey there must be continuing provision for carrying back through lumber manufacture the findings in any branch of forest research that will tend to better utilization.

Final Products

Waste in the industries which use lumber may be regarded as even more serious than in primary manufacture, because it involves for the most part the highest grade material and that after a very large amount of time and money have been devoted to its manufacture and distribution. In these industries there has been a series of investigations by individual corporations, associations, States, and Federal agencies. In varying degree both waste and utilization have been covered. The Forest Service has studied requirements as to sizes, quality of material, quantities, etc., and to a smaller extent the manufacturing processes in some 12 important industries and in less detail for 12 additional industries. Industries of the first class include the manufacture of chairs, refrigerators, furniture, kitchen cabinets, railroad cars, automobiles, and flooring. The Department of Commerce has been looking into the possibility of using short and odd lengths in house building. All this work is only a beginning. Much is already obsolete. What we need is a country-wide study which will carry through to the ultimate use, regardless of the diversity of the industries involved, all of the lumber output of our sawmills. We need to determine the actual requirements of service rather than those based on mere practice or preference. Conditions of production and use should be reconciled.

Small Dimension Stock

Intimately involved with lumber investigations, but of such significance as to warrant separate consideration, are investigations to show the possibility of manufacture at the sawmill of small, standard sizes for use in processes such as furniture manufacture. It has been customary to cut large quantities of lumber into these small-sized products. Losses of 50 per cent have been found in chair manufacture, and these are not believed to be unusual for this or other industries. Some of the advantages of manufacture to size at the mill are the possibility of using profitably the low-grade lumber and the shorter and poorer logs and trees which, if lumber were the sole product, would be consumed in the sawmill burner or left in the woods. A large saving may also be made in transportation costs. The multiplicity of sizes into which such stock is now cut by the manufacturing plants, probably totaling fully 50,000, and between many of which there are exceedingly small differences, must be so reduced that the sawmill may cut recognized standard sizes with reasonable assurance of markets.

The Forest Service has done considerable work on the small dimension stock problem with particular reference to its feasibility in the wood-turning and chair industries. A study has been made of the requirements from this standpoint of ten other important hardwood-using industries. The wood-turning industry itself has done a good deal of work. Apparently there is a large opportunity for savings through the direct manu-

facture at the sawmill of small dimension stock, provided only the necessary investigative basis can be supplied.

Other Materials

While of greatest importance, lumber and small dimension stock are only two of a rather large number of products which should be studied in accordance with the same general plan. Others are cooperage, veneers, handles, and the like. Relatively little work has been done on any of them.

Logging and Silviculture

The need for a new logging engineering which takes into account both the silvicultural requirements of the forest and better utilization has already been considered under Silviculture.

SEASONING

While a phase of manufacture, the seasoning of wood is so distinctive in its problems that it is discussed separately.

Air Seasoning

A large percentage of lumber and other timber products will for many years to come be air seasoned in spite of any conceivable developments in the kiln drying processes. Commercial air seasoning is exceedingly variable, has a large rule-of-thumb element, and has been too largely without investigative basis. There is a great possibility, therefore, of reducing waste and degrade by eliminating checking, warping, and blue staining. The Forest Service has been conducting extensive commercial-sized air seasoning experiments in various lumber-producing regions in cooperation with local associations and individual mills, and in New York State with Syracuse University. Enough has been done to give a reasonably good idea of the effect of important variables upon the drying rate and the degrade of the stock. While it is obviously not possible to vary the climatic conditions to which the stock is exposed, it is possible to control the extent to which these climatic conditions affect the stock, by varying such factors as the size and shape of the lumber pile. A great deal of additional study is required to work out the best possible system of piling and seasoning for each individual set of conditions and each species and grade.

Kiln Drying

The need for kiln drying arises from two main requirements. One is economic—to reduce freight cost; to reduce the quantities of lumber held and hence the investment; to reduce losses; and to fill orders on short notice. The other is physical—the necessity of having lumber drier than can be obtained by air seasoning in regions where the products are used in heated houses. For such regions and purposes lumber must of necessity be kiln dried even if it is first air dried.

Comparatively large and unnecessary losses are incurred in current kiln drying processes, as, for instance, in southern pine operations where degrade for uppers has run as high as 33 per cent and for common stock 22 per cent. Investigations to determine the causes and remedies for these losses have been under way for a number of years. These studies have been carried on largely by the Forest Service, commercial kiln companies, and various manufacturing concerns and associations to which improve-

ments in kiln drying processes are of importance. A reasonably satisfactory empirical understanding of the manner in which seasoning defects are brought about and of ways in which they can be avoided or remedied has been obtained. The general effect of variations in the controllable conditions, namely, temperature, circulation, and atmospheric humidity, is sufficiently understood to make it possible to draw up reasonably satisfactory drying schedules. Such schedules have been developed in the Forest Service for about 50 of the more important American species and additional schedules are being worked out.

Until recently the major portion of the work has been confined to upper grades of the various species and little attention has been devoted to the effect of knots and other defects upon the seasoning, and to the differences in conditions of use between upper and common grades. Especial attention is now being devoted to the seasoning of common grades of Douglas fir and of southern pine, and special drying schedules particularly suited to the respective grades have been developed.

There are many distinctive problems in the seasoning of stock of special sizes and shapes, such, for instance, as dimension squares of different species for furniture making, cooperage stock, cedar pencil slats, shade roller pickets, broom handles, veneer, golf club shafts and heads, hat block stock, and artificial limb blanks. To secure the most satisfactory results in these special cases, individual schedules and methods of handling must be worked out.

An important cause of present poor drying practice lies in inadequate kilns and equipment. The experimental development of drying schedules has carried with it several new types of kilns and the perfection of control apparatus. This is the work of dry kiln companies, instrument makers, and the Forest Service. Practically all effort has been centered on kilns and equipment for lumber drying. As the kiln drying of special forms, shapes, and sizes becomes more common, corresponding progress in drying equipment will have to follow.

While individual dry kiln manufacturers and users have much information concerning some elements of cost of kiln drying under different processes, nothing satisfactory has been published, and very little is available anywhere concerning one important phase of cost, steam consumption. The Forest Service has initiated studies to determine steam consumption under various conditions, and possibly later will extend the scope of cost determinations.

Seasoning and Coatings

It early became obvious that much of the trouble from checking was caused by too rapid evaporation from the end grain of the wood and consequent too rapid shrinkage. To overcome this a pitch mixture and several other coatings have been perfected by the Forest Service. It has been found more recently that control of the moisture gradient in the stock, i. e., the change in moisture content from the surface to the interior, by coating the entire piece produces materially better results in certain instances.

Seasoning and Properties

A long series of investigations involving about 250,000 strength tests has been made in the Forest Service on the effect of kiln drying upon strength. The work has been centered upon the determination, chiefly

during the war, of the effect of various drying schedules on aircraft woods such as spruce, Douglas fir, ash, and Port Orford cedar. These tests have shown that in general wood kiln-dried by suitable processes is equivalent in strength to carefully air-seasoned stock. It is not anticipated that additional tests of this character will be necessary. It is probable, however, that it will be found desirable to carry on from time to time special series of tests to determine the effect of various methods of seasoning upon such properties as resonance, hygroscopicity, and ability to stay in place.

Seasoning and Stains and Decay

Heavy degrading losses from blue stain, ranging from $10 to $40 per thousand board feet in high-grade stock, now frequently occur in air seasoning the various pines and spruces, red gum, basswood, cottonwood, poplar, and maple. These have been investigated over a period of years by the Bureau of Plant Industry and the Forest Service, in cooperation with various industrial manufacturing associations. Remedies lie partly in more prompt seasoning and partly in chemical treatments which will be discussed later.

An important cause of loss and degrade in both western yellow pine and sugar pine sapwood lies in a brown stain of apparently a chemical nature. One western yellow pine mill reports a degrade of 75 per cent in two high grades during the less favorable months. The cause should be determined authoritatively and promising preliminary findings should be perfected.

In General

A large amount of additional work on seasoning by all agencies equipped for research is necessary. For the immediate future it will necessarily have to be based on existing rather meagre fundamental knowledge of the laws governing heat transmission and moisture diffusion through wood and of the structural and other physical characteristics of the wood substance. It is probable, however, that large future developments in dry kilns and in kiln drying processes will be based on extensions of fundamental knowledge, and this may also be true to a smaller extent of air seasoning.

DESIGN

The efficient use of wood in design, obviously including the reduction of waste, is one of the chief functions in the application of fundamental data on strength. These fundamental data also have other important functions in other economic savings, as for example, the reduction in the shipping losses of commodities through the better design of containers, losses which, at the maximum a few years ago, resulted in railroad freight claims exceeding $100,000,000 a year in the United States.

Structural Timbers

All of the fundamental strength investigations of the Forest Service have been based on tests of small pieces of wood free from defects. Since it is practically impossible to obtain large sized structural timbers such as bridge stringers without some knots, checks, shakes and other defects, it is necessary to know within reasonable limits to what extent various defects will reduce theoretical strength. The Massachusetts Institute of Technology, Purdue and Columbia Universities, the Rensselaer Polytech-

nical Institute, the City of Portland, Oregon, and the Forest Service have accordingly made tests on large-sized pieces to get at these relationships. Those on beams have covered about 12 species and the effect upon strength of knots of various sizes in different parts of the beam are now fairly well known. Of the important defects least is known of the weakening caused by decay. Decay can reduce strength to zero, but how to estimate the effect in early stages is a complicated problem. Investigations are also needed of shear in checked beams to correct inaccuracies of the formula, particularly as the load approaches the support.

Of long wooden columns a few tests only have been made and these largely by the Forest Service. It has already been necessary to develop an entirely new formula. Studies of the twisting of columns of special form are necessary and will undoubtedly lead to the development of formulas for determining the strength of such columns and for avoiding twist.

Some work has recently been started in the Forest Service to determine the stresses in beams or columns submitted to both beam or bending and column or compression action. This work has led to the development of a maximum load chart. Work has also been done on the stresses in continuous beams—those which are supported at more than two points. This has also led to the development of a chart for use in calculating the strength of such beams.

An extensive series of Forest Service investigations has shown that correction factors must be applied to the existing stress formulas where the cross section of beams varies from the solid and rectangular, as in box and I-beams. Unquestionably other tests of this sort will have to be made, as, for example, of the influence of abrupt changes in cross sections.

In the strength of structural timbers preservative treatment may introduce a complicating factor. Tests by the Santa Fe Railroad and the Forest Service have shown that the preservative process beyond certain limits of steaming under pressure or boiling, and not the preservative itself, was responsible for the weakening.

The telephone companies have done most of the work in the testing of poles, although the Forest Service has contributed. Important facts have been brought out, such as the lack of appreciable deterioration in the strength of fire-killed lodgepole pine after standing ten years, if free from decay and insect attack, and the fact that a relatively little-used species such as lodgepole pine is fully as strong as the cedars hitherto most in demand. Tests on hickory wagon spokes made by the Forest Service showed an error of more than 50 per cent in the spoke-grading system in use, largely due to traditional prejudice and discrimination against red hickory. These and additional tests on mining timbers, cross arms, wagon shafts, poles, and axles are merely examples of a large number of tests of structural members that have already been or should be made as a basis for thoroughly efficient use.

Service Conditions and Behavior

Wood under all conditions of use is subjected to the influence of moisture, to which the various species respond and react with marked differences. Little is known of the inherent characteristics of species with respect to the rate of shrinking and swelling, the tendency of the grain

to raise, the development of checks and shakes, and the influence of restraints of loads, and of inequality of conditions in service. All of these characteristics are, however, of great importance in relation to satisfactory use, and are fundamental to design. In the establishment of working stresses for structural timbers, for example, the numerical interpretation of strength tests must be tempered by a consideration of these characteristics of wood. Research will disclose to what extent the reputation of the various species as reported by the trade is well founded.

In swelling, wood exerts forces of considerable magnitude when restrained. While these forces have a bearing on practically all uses, they become of particular importance in the design of such structures as stave pipes, tanks, and silos. Some data are available on the amount of shrinking and swelling of the different species with change in moisture, but the magnitude of the forces and their relation to design has never been determined. The solution of the problem involves an exploration of the maximum conditions as to stresses and permanent deformations or mashing caused by swelling of the wood, and the correlation of this basic data with the conditions of use.

Working Stresses

The members of a structure, such as beams and columns, are subjected to loads which they should be of sufficient size to carry safely, and for economy they should be no larger than necessary. Working stresses are the stresses that timbers in structures can safely be allowed to carry.

Starting with the strength of the clear material, deductions are made for defects, variability, unfavorable conditions, loading, and a factor of safety. These deductions make the safe working stresses for structural timber of a good grade about one-fifth or one-sixth of the strength of the clear green material. Working stresses have been published by the Forest Service for about 30 species. Their application depends primarily upon the availability and use of timber graded under new structural timber rules recently formulated. Work of the future in working stresses will consist primarily in such modifications of the existing stresses as new test data may warrant.

Joints and Fastenings

A vast amount of wood is used in built-up or manufactured articles where strength is required. Joints and fastenings are the weakest part of built-up construction and usually control design, but practically no investigative work has been done on them. The standard engineering works on timber framing by Jacoby and by Dewell are not based on extensive tests. Tests are needed, therefore, on a large number of types of joints and fastenings, on the comparative efficiency of dowel, mortice, and tenon joints, on glues, on the holding power of nails and screws of various types, and on the most effective methods of bolting. The range of the tests must be broad enough to include furniture, sashes and doors, vehicles, and implement parts in addition to timber framing. A very large amount of work is required in this field.

Fabrication by Glues

It is possible to build up large articles and even structural timbers successfully by gluing. It might be possible to build up curved stock by

bending thin pieces of wood and gluing them at the same time. Much material in small sizes now wasted in logging operations and all the way through many forms of lumber remanufacture could be so utilized, especially if highly moisture resistant and durable glues could be developed. Some progress has been made in this direction by commercial concerns and by the Forest Service, but much more work is needed. There is also great need for isolating and studying separately the factors including species that influence gluing, the preparation of the gluing surface, the amount of glue spread, assembly time, use of heat, pressure, and drying time. Such investigations if combined with wood structure studies would gradually solve the difficulties of gluing different species and define the conditions necessary to satisfactory results.

Structural Units

The stresses in built-up members such as trusses and girders with rigid joints, are so complex as to preclude satisfactory analysis. Tests must therefore be resorted to in order to improve design. Tests disclose weak points which can then be strengthened in the light of all the knowledge available on distribution of stresses in wood. The Forest Service has made tests on built-up airplane parts where strength in relation to weight is vital both for safety and flying efficiency; and it has been possible as a result to recommend great improvements in design. As rapidly as possible a large series of tests should be provided for on complete structural units such as roof trusses and built-up girders, as a basis for safe construction with minimum wood consumption.

Shipping Containers

Special test methods, including equipment, have been developed in the Forest Service and are being followed by a number of commercial concerns to determine the resistance of various shipping container designs to the variable stresses which they encounter in service. A nailing and strapping schedule for boxes has been developed and formulas derived for determining the thickness of lumber of different species for average commodities and sizes. In specific instances the lumber requirements for boxes have been reduced nearly one-third, in others the capacity of the box to stand shipping hazards has been increased many times. The principles of an effective corner and of diagonal braces in crates, two points of weakness in ordinary construction, are important developments to date. A large amount of work remains. Investigations of barrels, baskets, and fiber containers have hardly begun.

3. WOOD AS A CHEMICAL SUBSTANCE

The most effective use of wood presupposes a thorough knowledge of its chemical composition, a knowledge which is still far from adequate. A large fund of information has been accumulated about the reactions which wood undergoes when treated according to the processes used by the several chemical wood-using industries, but the information is largely empirical and does not lend itself to correlation nor shed much light on the composition of wood.

Recent work directly on the chemistry of wood by the Forest Service and California, Yale, and Syracuse Universities has begun to extend our knowledge in that field and has made it possible to generalize to a certain extent. The following brief statements on each of the several fields of wood chemistry will show the extent of present knowledge derived from research in both the United States and Europe and indicate future problems.

General Composition

In determining the chemical composition of wood there are fairly well standardized methods by which may be determined certain aggregates or groups such as cellulose, lignin, methoxyl, and acetyl. It is recognized, however, that the crude aggregates, cellulose and lignin, may vary in composition in different samples of wood and that the statement on the chemical composition of wood made in terms of such aggregates cannot be entirely satisfactory. We do have, however, very complete analyses of different species of wood, of heartwood and sapwood, and of spring wood and summer wood, and for comparative purposes these analyses are satisfactory. It has been found, for instance, that the main variation between different species is between the hardwoods and the softwoods, and that there is no great variation between individual species of either of these two groups. The general differences between the two groups are that the hardwoods have less lignin, more pentosan, methoxyl, and acetyl than the softwoods. The softwood cellulose also contains mannan, which is not commonly found in any of the hardwoods. The greatest chemical difference between species and between heartwood and sapwood lies in the extractives, the material not a part of the fibrous structure of the wood and extractable by neutral solvents. These are the substances which cause the marked differences in color, odor, durability, and resistance to chemical action.

Extractives

Apparently there is not much more useful information to be obtained by making additional comparative analyses for other species of heartwood, sapwood, spring wood, and summer wood. It is important, however, that we know more about the composition of the various extractives, especially those poorly characterized constituents usually described as starch, sugar, gums, and albumen. We should also know more about the chemical composition of the well characterized extractives from such species as redwood, cypress, and red cedar, which have such an influence on the properties of the wood.

Recent work under way in the Forest Service on the water soluble material in redwood has shown that the extract contains many unlooked-for chemical compounds. It is a possibility that some of them are responsible for the durability of this wood. It may also be that many other durable woods depend largely upon the nature of the extractives.

Tannins and dyes are extractives, and one or both are found in many woods or barks such as the chestnut, chestnut oak, and hemlock. The whole tannin problem is greatly complicated by the difference in the tannins from different species, so that this is a highly specialized field which

runs quickly into involved problems of fundamental chemistry. The vegetable dyes also present a wide range of difficult chemical problems on the properties of the dyes from distinct species, all of which differ.

Cellulose and Lignin

Although we have standard chemical methods for determining cellulose and lignin, yet it is admitted that these materials, as determined by the analytical methods, may vary considerably in composition and that we know very little about their constitution. We have a little information on the way in which crude cellulose varies in different groups of species, but much remains to be done on the relationship between the pure cellulose and the other carbohydrates which are so closely associated with it. The composition and constitution of pure cellulose or cotton cellulose has received much attention, and while the problem is not solved we have much light on it. The conclusions reached probably apply to that part of the wood cellulose which resembles cotton cellulose but not to the other carbohydrates in the wood cellulose. The way in which the pentosan, mannan, and the readily hydrolyzed glucosan are attached to the pure cellulose is a subject about which there is much controversy and little information. Aside from its scientific value this problem also has a direct bearing on the production of alcohol and paper pulp from wood.

The constitution of lignin and its relationship to the other wood components is a field in which little progress has been made. One reason for this is that so far it has been impossible to separate lignin from cellulose, except by methods which evidently have considerable effect on the composition of the lignin and therefore no one has had a pure lignin with which to start research. The method of combination between the lignin and the cellulose has been a subject of controversy for many years, but there is still very little information on the subject. There have recently been developed, however, special methods of research such as the X-ray photographs which may be of great value in solving this problem. We are also beginning to obtain some purely chemical data which throw some light on this method of combination. This general subject has a strong practical bearing on chemical pulping methods.

We have just made a beginning in determining the location of different chemical constituents of wood in the wood structure. We have found, for instance, that part of the lignin exists as free lignin in one part of the wood structure while the rest of the lignin is combined homogeneously with cellulose in another part of the wood. We have practically no information, however, on the distribution of the other constituents, except of course those extractives which are not a part of the cell wall.

Wood as a Colloid

Wood is undoubtedly a colloid and should be studied by colloid-chemical methods, but nothing has been done about it. It has even been claimed that the formation of wood in the tree is nothing but the colloidal absorption of various sap constituents by cellulose. Cellulose, and especially the cellulose esters and solutions used in making artificial silk and cellulose lacquers, have been studied somewhat as colloidal substances, but almost no work has been done on wood as such. This field offers several promising openings for research. It has been suggested, for instance, that many of the chemical decompositions of wood might take place differently in speed, distance, or composition of products if the condition of the surface

under treatment, a colloidal condition, could be properly modified previous to the treatment.

Obscure relationships of a colloidal nature between pulp or wood fibers and moisture are involved in the changes which take place, for example, in the beating or hydration of pulps. Great differences in properties, appearance and utility may be obtained. Considerable work has been done by many agencies, largely empirical, and bearing on specific problems but much more of a broad and fundamental character is possible and should be undertaken.

Closely allied with the colloid chemistry of wood is the consideration already discussed, of wood as a product of life processes rather than merely a raw material for further chemical treatment. On the bio-chemistry of wood we have practically no information. How wood is formed, the relation between growth conditions and chemical composition and chemical properties, the physiological meaning of the extractives—these are important fundamental problems that lie all in the future.

Distillation, Hydrolysis, etc.

The beginnings of hypotheses concerning the mechanisms of wood hydrolysis, distillation, delignification, and decay are being developed. Purely scientific studies along these lines would give information on the detailed mechanism of the chemical pulping processes, wood distillation, the production of sugar and alcohol from wood, and wood decay, and would serve as a foundation for special work on these subjects from the point of view of the process rather than the material. Upon wood hydrolysis, for example, and one of its final products, ethyl alcohol, we may some time wish to draw heavily for a substitute motor fuel.

Considered as a whole, the most essential aspects of the fundamental chemistry of wood are quite largely problems of the future. Empirical knowledge of the chemistry of wood has already made available such products as paper and grain alcohol. The prospects of far greater services to mankind in these and many additional ways, if fundamental knowledge can be enlarged, are sufficiently alluring to warrant thoroughgoing exploration.

4. THE USE OF WOOD AS A CHEMICAL SUBSTANCE

Most forms of wood utilization involving chemical change are very recent. While still small in total volume, not over 3 1/3 per cent of the total drain on our forests, it is well within the range of possibilities that utilization after chemical change may prove the ultimate key to the use of an immense volume of wood now wasted. A thoroughly satisfactory moulded product suitable for various building purposes might alone be a large factor. For pulp, viscose, alcohol, and other chemical products it is possible to utilize small or finely divided material for which at present there seems to be little other opportunity for profitable use.

WOOD IN PULP AND PAPER

Pulp and paper rank high in importance among the products derived from wood by the chemical processes. Fifty-one per cent of all the pulpwood needed to meet American paper requirements in 1922 came from foreign countries as pulpwood, pulp, or paper. Seventy-eight per cent of

our total pulpwood requirements depend on the spruces, firs, and hemlocks for sulphite and mechanical pulp. The pulp and paper industry is now centered largely in the Northeast and the Lake States where the supplies of these species is limited. Accordingly any research which will increase the pulp yields from the spruce-fir-hemlock group or permit the manufacture of substitute pulps from the jack pine or hardwoods of the Northeast or Lake States, or make practicable the utilization of other species in other regions such as the South, ought to receive great emphasis in the immediate future. Even with new industrial developments growing out of successful investigations along these lines we shall need much or all of the spruces, firs, and hemlocks in the Pacific Northwest and in Alaska to meet our future paper requirements if we are to be self-supporting or anything approaching it.

Suitability of American Woods for Pulp

For many years a systematic survey of the suitability of the American woods for pulp making under existing processes has been under way in the Forest Service. Under one or more of these processes it has covered about 90 of those species which occur in sufficient quantities to make pulp manufacture commercially feasible. These investigations have shown not only the variation in the pulping qualities of each species by the different processes but have given comparative yields, the qualities of the pulp, etc. Modifications of existing or the development of new pulp-making processes will necessitate a continuation of the survey.

Improved or New Pulping Processes

Many years of research, mainly at industrial plants and largely empirical, underlie the three common chemical pulping processes, soda, sulphite, and sulphate. This has led to the standardization of processes chiefly to insure uniformity of the product, to minor improvements in the processes themselves, and to a large number of special products such as cellucotton and paper for textiles. The improvement in the processes has, however, been relatively slight since their introduction into the United States beginning with the soda process in 1854.

Because of this lack of improvement and to supplement the empirical knowledge on which these processes rest, the Forest Service has undertaken two main lines of investigation. The first includes several phases of the fundamental chemistry of wood already described. The second is an intensive study of the action of pulping chemicals on wood. Out of the combined results should come improvements in existing processes and possibly entirely new processes.

Action of Sulphites on Wood.—The latter class of research has included the action of the sulphites on wood. If intensively carried out it should give a thoroughgoing idea of the chemical reaction throughout the entire cooking process. An example of a new or modified process which has already resulted from this work is given later.

The sulphite process dissolves not only most of the lignin but also about one-fourth of the cellulose material, so that a total of over 50 per cent of the original weight of the wood is lost. The increase of yields is, therefore, of outstanding importance. Once the action of the chemcials on the wood is thoroughly understood, pulps can possibly be made which will contain nearly all of the cellulose and as much of the lignin as may be desired.

Another outstanding problem is to increase the number of species which may be satisfactorily pulped with sulphite liquors. The resinous pines constitute one important group of trees which it would be very desirable to add to the spruces, firs, and hemlocks which are now used. A difficulty which unfortunately restricts such use is the high pitch content which prevents uniform cooking and also causes operating troubles in the paper mill. More or less work has therefore been done on the jack pine of the Lake States as a representative resinous pine. Results already obtained are promising and should be continued until the pitch difficulty has been overcome. The work, however, should be extended to other groups of trees.

Action of the Alkaline Chemicals on Wood.—As in the case of the sulphite chemicals, an intensive study of the action of the alkaline chemicals on wood is required. Here again the findings may lead at any time to striking improvements of existing processes or the suggestion of entirely new and improved processes.

As with the sulphite chemicals, an increase in yields is of great importance. It should not be necessary to continue indefinitely under processes which yield only approximately half of the original weight of the wood.

Probably the outstanding present problem of the alkaline chemicals is to obtain from species on which they are now used pulps which can be substituted for those from spruce. Another problem is to extend their effective use to other species. An example of the former is the attempt to obtain from the resinous pines a strong, light-colored pulp in which the resin difficulties have been overcome. Success might make possible an essentially new pulp industry in the extensive southern pine forests. Incidental to such investigations is elimination or reduction of the odors in sulphate pulp manufacture, which now restrict its use to sparsely settled localities.

Still another possibility of extending the scope of the alkaline process, and thus reducing the pressure upon the spruces, is that of producing by the soda process pulps as strong as those obtained in the sulphate process.

Operating efficiency is always a problem. An example of possibilities is shown by laboratory results already obtained by the Forest Service and confirmed in mill tests, which indicate a saving of a large proportion of the heat necessary to cook by the alkaline processes, provided the cooking chemicals are first forced under pressure into the chips and the steaming done after withdrawal of the excess liquor. Wider application of this principle should also be encouraged in the sulphite process.

Combined Chemical and Mechanical Pulping.—One of the suggestions that has come out of the intensive study of the pulping chemicals by the Forest Service is a combination of chemical and mechanical pulping. Investigations have, therefore, been under way with sodium sulphite as the primary pulping chemical to determine the possibility of softening the chips enough so that they can be readily disintegrated mechanically to bright-colored, easily bleaching pulps. Yields of over 80 per cent of the unbleached product have been obtained. Preliminary work has been done on jack pine, aspen and black gum, but it is entirely possible that the method may prove equally suitable to the northern hardwoods—beech, birch, and maple—and to certain southern hardwoods and pines.

Bleaching.—Chlorine or hypochlorites are almost universally used to

bleach pulp, and bleaching methods have been the occasion of a large amount of research by industrial concerns. Commonly in commercial operations the pulp is cooked so thoroughly that only small amounts of bleach are required. A thorough investigation is badly needed of the possibility of modifications of both cooking and bleaching to give higher yields of bleached pulp at lower cost. A method of bleaching resinous pines would greatly stimulate their use and distribute pulpwood demands more widely.

Mechanical Pulp.—Since spruce is now used almost exclusively for mechanical pulp, a material enlargement of the number of species used would be very advantageous to both public and industrial policy. Investigative efforts to grind such resinous woods as the jack pine under conditions which will prevent the coagulation of pitch in troublesome particles should be undertaken. Hardwoods, including aspen, are not commonly considered suitable for mechanical pulp because they are short-fibered and although requiring high-power consumption give only pulps of low strength. Methods of grinding should therefore be investigated to determine to what extent these difficulties can be overcome and the hardwoods used to supplement the rapidly diminishing supply of spruce.

Chemical and Physical Properties of Pulps

At present the only reliable method of determining the papermaking value of pulps is by actually making them into paper. The development of simple, easily applied tests should be attempted through work on the chemical and physical properties of pulps.

The Use of Waste Products

Bark has ordinarily been a total waste in pulp manufacture. A small amount of investigative work has been done to develop methods of using bark for fuel or for special products. There is opportunity for much more.

Over 40 per cent of the spruce and balsam in areas recently infested with the spruce budworm has been killed and if not used within the next few years will be a total loss. This is merely one example of the advantage of being able to utilize decayed wood. Reliable criteria are needed, however, by which decayed pulpwood can be selected and graded upon the basis of pulping value.

Some work has been done to determine the feasibility of using for pulp the chips which have already served one purpose. Cases in point are chestnut waste from tannic extract plants and the southern pine waste from which turpentine has been removed by steam distillation, in which the suitability for pulping has already been shown.

The utilization of sawmill waste during the six years prior to 1923 actually fell off about 56 per cent. Both economic and technical difficulties make satisfactory utilization difficult but the opportunity is so large that investigations of ways and means are more than justified.

The re-use of old paper lessens the demand upon the forest for new pulp. In the twenty years ending in 1919 the growing shortage of pulpwood supplies resulted in an increased use of old paper of 420 per cent. Investigations by the Forest Service have shown the technical feasibility of de-inking print paper, but the commercial feasibility awaits demonstration. Possibly other investigations will be needed to remove other technical obstacles to a further use of old paper.

Although waste sulphite liquor contains over 50 per cent of the original weight of the wood in solution, it has ordinarily been dumped into streams, thereby resulting not only in waste but also in a serious problem of contamination. The recovery of this liquor is, therefore, another problem of great importance. A very large amount of research, mainly by industrial plants, has brought one apparently promising solution. It is uncertain how much more work will be required.

Since the black liquor from the alkaline processes also contains in solution over 50 per cent of the original weight of the wood, but has at present no other use than as fuel to evaporate the liquor in recovering the alkali, an opportunity is presented for working out higher forms of use. During the war a process for the recovery of valuable by-products by destructive distillation was developed on a commercial scale by a paper and pulp company. Investigations should be continued and every effort made to secure a wide adoption of the results in commercial practice.

Paper

While much investigative work has been done on such paper problems as loading, calendaring, testing, and satisfactory specifications by many industrial concerns, the Bureau of Standards, and the Bureau of Chemistry, there is much about paper and its properties and the possibilities of manipulation to secure closer adaptation to actual requirements that is still unknown and should be investigated. The physical and chemical properties of paper can be little less complex than those of pulp or wood.

Other Pulp Products

Paper, however, is only one of a rapidly growing number of products for which pulp is the raw material. Artificial silks made from solutions of pulp or cotton reached in 1924 a total of 45 per cent of the total silk consumed in the United States. The production from viscose of a fabric without luster and resembling wool is now claimed to be a demonstrated commercial possibility. During the war considerable work was done by the War Department and some by the munitions companies on the use of pulp for explosives as a potential substitute for cotton linters.

By molding under pressure finely divided wood in the form of pulp or sawdust combined with binders or adhesives, a wide variety of useful articles may be made. Some such products are now being produced industrially on a small scale under secret methods. Investigations should be greatly enlarged to develop satisfactory methods of manufacture and to determine properties and fields of usefulness of the products.

These are merely examples of the rapidly enlarging list of products which can advantageously be made from pulp. Each requires investigations more or less intensive.

THE USE OF EXTRACTIVES

For many years the United States depended almost entirely upon native vegetable tannins and much investigative work, most of it empirical, into the properties of these tannins and their manipulation was done by industrial concerns. Where vegetable tannins are to be used, the application of each, because of the difference in properties, must be worked out separately upon different leathers. There are certain obvious advantages in the ability to use our native products, particularly in times of emergency when imports are difficult.

Vegetable dyes, once of first importance, have now been replaced by synthetic coal-tar dyes. Successful commercial use of vegetable dyes would depend upon similar research, although there now seems to be little likelihood of successful competition with synthetic dyes.

In some instances it may be desirable to fix highly colored extractives in the wood by chemical treatment and thus prevent undesirable leaching. For instance, a wood that gives rise to a highly colored water solution is not always suitable for tanks, washing machines, and other apparatus used for the storage of liquids. There is also the possibility that the fixation of colored extractives might prevent the staining of paint.

Many tree species contain in their wood other extractives of various sorts. Work by the Forest Service and by other agencies on the galactan of the western larch has resulted in the commercial manufacture of mucic acid, a substance which competes with tartaric acid for baking powder. Undoubtedly quite a large number of other extractives should be investigated.

The resin obtained by naval stores operations from living longleaf and slash pines, while not generally considered as an extractive, will be discussed here. It ranks first in the value of output among the American products of the "extractives" group. Considerable work has been done by the Forest Service looking towards the improvement of field turpentining methods. This has given a fairly good idea of the best width and depth of chipping for use in the so-called "American" method. A good beginning has been made on yields from trees of different diameters and considerable information has been made available on the effect of frequency of chipping upon output. All of this work, however, needs to be rounded out, and the possibilities of more or less radical improvements in the common American method need to be tested. All the problems involved should be checked against climate, soil, and other environmental conditions, against the physiological processes of the tree, and finally brought into harmony with good silvicultural practice. Just what relationships exist between turpentining and the quality of the lumber or other wood products which can later be cut from the tree should be determined.

The technical feasibility of using some of the western pines for naval stores has been shown but the economic practicability remains to be demonstrated. Considerable work by the Bureau of Chemistry has shown the way to replace the primitive methods common in commercial practice by much more effective methods of distillation but much more work is necessary. Commercial concerns have done research into the better uses of naval stores in such products as soaps, varnish, printers' inks, etc. The naval stores industry has recently initiated research to find new uses for its products.

DISTILLATION PRODUCTS

Distillation is of two kinds: Destructive distillation breaks down the wood entirely and produces a variety of chemical products; steam distillation merely removes such extractives as resin.

Hardwoods

The distillation of hardwoods now produces three main products, wood alcohol, acetate of lime, and charcoal. Charcoal keeps a fairly steady

market but the other two fluctuate widely in demand and price. This industry, which could use large amounts of wood waste, is now seriously threatened by competition with new synthetic products. Operations must be radically changed or made vastly more efficient to meet this situation. Research might bring greater efficiency in cheaper processes, increased yields, or improved products. One wood distillation product, the tar, which is now used mostly for fuel, might be developed into one of the main products. A small proportion of this tar is being made into flotation oils, wood preservatives, transformer oils, wood pitch, etc., but more information on its composition and properties is needed before any large proportion can be utilized more profitably.

Resinous Woods

There are two fairly distinct forms of resinous wood distillation. In destructive distillation one of the problems is the standardization of products. At present each plant has its own line of products with special names such as akrosite, and there are no standard products or specifications. The commercial processes are crude and attempts to improve them would be more satisfactory if the products to be made were determined. Beyond these is of course the possibility of entirely new products.

Steam distillation and extraction is a comparatively new process, the greatest difficulty of which lies in the quality of its rosin, which is sufficiently different from the standard commercial rosin in color and some other properties so that it does not have many commercial uses. A study of this rosin to develop a bleaching and refining method is needed. If successful it would aid in the utilization of wood which is now largely wasted. Other promising studies are on the use of solvents other than the gasoline now used and modifications of the process so that the extracted chips may be suitable for pulp chips.

ALCOHOL AND OTHER HYDROLYTIC PRODUCTS

Wood hydrolysis has among other possibilities some promise for the utilization of softwood mill waste. Work has been done by two or more commercial concerns and by the Forest Service. The opportunity for increasing the yield of the main product, ethyl or grain alcohol, seems to be good.

An adaptation of this process for the manufacture of cattle food has been proposed by the Forest Service, and feeding tests on the products have been made by the University of Wisconsin, the Bureau of Animal Industry, and the Massachusetts Agricultural College. If these are successful further work will be required for developing the best commercial process.

5. THE PRESERVATION OF WOOD

In logging and manufacture, and thereafter for much longer periods of use, wood and its products are subject to loss through decay, to damage by insects or marine borers, and to destruction by fire. Even separately, but much more in the aggregate, these losses are so large that resulting replacements alone constitute an enormous and largely unnecessary drain

on our forests. An exceedingly important branch of forest products research must therefore deal with efforts to prevent or minimize such losses.

WOOD-DESTROYING ORGANISMS

Fungi

All kinds of forest products research present problems which cannot be solved without more thorough knowledge of wood pathology in its most fundamental aspects. The prevention or the reduction of the deterioration in lumber and other forest products by wood-rotting and wood-staining fungi can be accomplished only through accurate knowledge of the organisms which attack wood, what they are, how they grow, and of the conditions which are favorable or unfavorable to their dissemination and growth.

Knowledge of the organisms themselves is by no means meager, as a result of many years' study by pathologists in the government and state services and in the universities. As soon as possible, however, all of the rots, stains, and molds which attack wood or wood in such modified forms as pulp should be classified and described. Their life histories should be worked out. The character of their attack on different woods should be studied, to aid in recognizing them.

About the actual growth processes of the fungi which attack wood and their reactions to environment we know comparatively little. The moisture content of wood in general governs the rapidity of fungus action. Wood which is thoroughly wet will not rot, nor will that below the moisture content favorable to the growth of the organisms. Some fungi are easily killed by heat while others are resistant. In general, blue stain fungi and molds are more resistant to both wet and dry heat than the wood-destroying fungi. Preliminary experiments have indicated the time and temperature conditions necessary to sterilize infected wood. The application of results of these experiments and others now under way seem to promise much improvement in the utilization of certain classes of wood now culled as defective. Much additional research is necessary, however, to determine the moisture, temperature, light, and other environmental relations of fungi which rot or stain lumber and other forest products.

Radical differences have been found in the relative resistance of fungi to toxic substances, but the nature of the resistance and the nature of the toxic action are not known. Laboratory methods for testing the relative toxicity of certain chemicals have been worked out primarily in the Bureau of Plant Industry. Such tests, however, do not explain the process of killing. More comprehensive investigations by the physiologist and chemist must therefore cover the physiological reactions of wood-rotting and wood-staining fungi to toxic substances.

Apparently all wood-destroying fungi attack the cellulose in wood, while a few attack the lignin also. As a result the pulping properties of wood are, for example, affected more quickly by some fungi than by others. In some cases the fungus destroys the cell wall by boring through or corroding it, and in others it produces some substance which seems to dissolve the cementing substance in or between the cell walls. Knowledge of the enzymes produced and their action on wood is very imperfect. The entire process of decay in wood must therefore be studied jointly by the chemist and the pathologist. Particular attention should be paid to the hypothesis

that the attacking fungi leave behind them enzymes which complete the destruction of the wood by a more or less continuous catalytic action even when the fungous mycelium has entirely disappeared. The possibility of action by molds and bacteria as follow-up agents which break down infested wood should also be investigated.

The mechanical properties of wood are affected much more quickly by some fungi than by others. The common red heart or ring scale fungus, for example, apparently causes but little weakness in certain strength properties in the early stages of decay, and the proper utilization of wood so infected offers a means of salvaging immense quantities of material which are now rejected as worthless. Microscopic evidence of decay is not paralleled by the effect on strength, at least in the earlier stages. Since investigations so far conducted have developed no mechanical means for determining the degree of decay in any given piece of wood, they must be continued.

The Bureau of Plant Industry has recently made a preliminary estimate, based on all of the data available, of the amount of wood needed each year in the United States to replace material which has gone to pieces on account of decay. The total of 4 billion cubic feet is approximately 16½ per cent of the annual drain on the forests. The basis for this estimate was necessarily tentative, and only a thoroughgoing survey can obtain the detailed information which will be required for a thoroughly satisfactory total. Furthermore, such a survey should point out specifically the fungi which cause greatest damage and the processes and classes of use where losses are heaviest.

Insects

The Bureau of Entomology estimates at $45,000,000 annually the losses from insects in the United States on forest products such as lumber, construction material, mining timbers, etc. Practically all round timber, lumber, wood, and pulp products are subject to attack. Termites, for example, which operate principally in our more southern States, the Mississippi Valley, and California may almost destroy timber, leaving nothing but an outer shell. But hardly less destructive attacks are also made by pin worms, wood-boring grubs, powder-post beetles, and carpenter ants.

Just as for insects which attack the living trees, there is the necessity for the classification and description of the insects which damage forest products, and of knowledge of their distribution, their life histories, and the environmental conditions which are favorable or unfavorable to their development. The life histories and environments must be studied with particular reference to points which may be subject to the easiest and most effective prevention or control. During the past twenty years a good deal of work along this line has been done by the Bureau of Entomology and by entomologists connected with universities and other institutions.

Such knowledge as we have on the sum total of damage and the part which various insects play in this is based on far too meager data. It should be supplemented as soon as possible by systematic surveys covering the entire country and all classes of insects.

Beyond this is the same need as with fungi to determine the substances

which are toxic or obnoxious to the insects which cause damage, as well as studies of the toxic constituents of untreated woods resistant to insect attack. Investigations of this character have been begun but much more work and on a larger scale is necessary.

Recent investigations at the University of Minnesota have shown a close relationship between wood destroying insects and fungi. The boring insects carry fungi into the wood and greatly increase the amount and rate of decay. The full extent of such relationships must be worked out.

Marine Borers

In many places, on both the Atlantic and Pacific coasts, timber used in marine structures is attacked by marine boring animals. In San Francisco harbor alone the damage within the last few years has been estimated at $25,000,000.

The most destructive marine borers common to both coasts are the mollusks Teredo and Bankia, commonly known as "shipworms," and the crustaceans Limnoria and Chelura, commonly known as "wood lice.'

Since shipworms enter the timber as minute young and burrow and grow but never enlarge the entrance hole, the interior may be honeycombed with practically no outside evidence. Piles 14 inches in diameter have been destroyed in a few months. Wood lice bore just beneath the surface, which is weakened and washed away.

The requirements for future research include, as with other organisms which attack wood, a full knowledge of the organisms themselves, their life histories, and of favorable or unfavorable environmental conditions. A knowledge of the toxicity of preservatives must be obtained for the particular borers against which protection is desired, also of the leaching or stability of the preservatives in sea water, etc. Considerable work has been done along practically all of these lines during the past few years by quite a large number of investigators. In 1911 the Forest Service started experiments on the efficiency of various preservatives when used for protecting piling specimens under service conditions, by placing specimens in a number of harbors on the Atlantic coast, the Gulf of Mexico, and the Pacific Coast. These tests have brought out some of the most important factors underlying satisfactory preservation. Much of the work of various investigators has been coordinated in the last few years in the San Francisco Bay Marine Piling Committee and in a special "Committee on Marine Piling Investigations" set up by the National Research Council. Under the San Francisco committee a series of comprehensive investigations have included such things as the life histories of marine borers and service tests of a number of preservatives. Both committees have published comprehensive reports. It is within the truth to say that only a beginning has been made on the fundamental aspects of the marine borer problem.

The Durability of Woods

Information on the life or relative durability of different species of woods under the same conditions, which in a sense is merely an expression of the natural resistance of the wood to destructive organisms, is very meager, although necessary to the most efficient utilization. While perhaps the need is greatest for studies of decay, much the same considera-

tions hold for insect and marine borer attacks. Something is known from experience in using wood and from miscellaneous service tests, but a satisfactory scientific comparison has never been made on an adequate scale, although it has been attempted from time to time by a number of organizations. A more comprehensive and thoroughgoing series of tests is needed in which a considerable number of specimens from all the important commercial American species will be set in the soil and exposed to the weather and placed in sea water simultaneously at locations so distributed throughout the country as to represent the various climatic and other conditions.

This series of tests should supplement chemical investigations to determine the character and the toxicity of the natural protective material in each of the durable woods. This series should include tests with pure cultures of various fungi, and similar tests with insects and marine borers if a satisfactory technique can be worked out. Some work of this kind has been carried on by the Bureau of Plant Industry and the Forest Service.

PROTECTION AGAINST WOOD-DESTROYING ORGANISMS

The protective measures which are outlined below apply in varying degree against different wood-destroying organisms. For example, preservative treatment with creosote may be effective alike against fungi, insects, and marine borers. Where measures discussed do not apply for any one or two of these, it will be clear from the context. In any case the research required will be similar for all, at least in general form.

Sanitation

The first important means of reducing losses from decay or insects is through sanitary measures which will prevent fungus infection or insect attack, including such measures as clean storage yards, and storage under conditions unfavorable to the attack of insects which may or may not carry fungus infections. The importance of sanitary regulations for the storage of lumber and other forest products is too little realized. Obviously in the South, where moisture and temperature are favorable to the development of fungi, more stringent regulations will be necessary than in the cooler portions of the United States. Danger of infection begins as soon as the tree is cut. Losses occur in a long list of such products as logs, lumber, fuel, poles, posts, ties, pulpwood, and pulp. Good methods of air seasoning and storage for lumber imply yards kept clear of infected material. For pulpwood also, which now is frequently stored in yards with rotten wood, sanitation requires the removal of infected material. In many instances pulpwood which has been barked should be stored in well-ventilated piles rather than in heaps. In other instances the conical heaps of pulpwood can of course be sprayed and kept wet enough to avoid decay, or the wood can be stored under water. The superiority of each method depends upon conditions.

The Bureau of Plant Industry has done practically all of the work so far attempted on methods of sanitation for lumber in storage and in buildings, and for pulpwood, pulp, and poles. To work out practical methods of sanitation applicable to storage of forest products requires a great deal more study. Much of the success which should attend the

application of such measures depends upon an understanding of the environmental conditions which are favorable or unfavorable to the development of different species of fungi and insects.

Preservatives

Sanitary measures alone, however, are not sufficient and must be supplemented by treatment with preservatives, the function of which is to check or retard the growth of decay-producing and of wood-staining fungi or to prevent the attacks of insects and marine borers. This may be done by impregnating the wood with a chemical which is poisonous to the organisms. Hundreds of chemicals and compounds have been advocated and tested as wood preservatives by many commercial and public organizations and new ones are constantly being brought forward. So far, however, only a few have been found which possess sufficient merit to justify their use. Creosote, of which about 160 million gallons were consumed in the United States in 1924, is the most commonly used wood preservative against decay and marine borers for such products as ties, poles, posts, paving blocks, piling, and mine and structural timbers. It is also one of the most effective preservatives against insects. Zinc chloride, which is ordinarily used only against fungi, comes second, with a consumption of about 33 million pounds in the same year.

Among the factors determining the value of a preservative are toxicity, volatility, permanence, leaching, effect on metals, ease of injection into wood, electrical conductivity, susceptibility to subsequent finishes, odor, inflammability, danger to health of men or animals, and effect on the strength of wood.

Considerable work has been done in the Forest Service on the fundamental chemistry of wood preservatives, including their chemical composition and toxicity to fungi, and from this a theory of the general mechanism of the protection of wood by preservatives has been developed. It is now possible, for instance, to say with considerable exactness what the toxic principles of coal-tar creosote are, so far as the wood rots are concerned. An extensive survey has been made of the gas oils from American petroleums, and preliminary work has been started to determine the fundamental factors governing the permanence of preservatives.

A complete study of toxicity, chemical stability, volatility, and leaching of injected preservatives has been handicapped by our lack of knowledge of wood structure and the movement of solutions in it. Progress in analysis of these factors in preservative action will follow close behind progress in the fundamental knowledge of wood. Ultimately the factors in preservative action should be understood to an extent which will enable any preservative to be evaluated by means of laboratory tests.

A rather comprehensive study of suitable preservatives against the decay of pulp has recently been made by the American Paper and Pulp Association, the Bureau of Plant Industry, and the Forest Service, and two or three cheap and otherwise satisfactory materials have been found.

Preservatives against decay which are reasonably satisfactory for many purposes are now available, but an odorless preservative which can be painted over is badly needed for such parts in house construction as porches, steps, sills, etc., where the odor and inability to take paint are

against creosote. Other new preservatives will undoubtedly be necessary to meet other special needs of fungus or insect menace.

Preservative Processes

A systematic series of tests to isolate the controlling variables in the injection of zinc chloride against decay have been made for two species of wood by the Forest Service. Similar tests are badly needed for creosote. The controllable variables are the character, condition, and temperature of the wood, preliminary air pressure, steaming time and temperature, vacuum, pressure, temperature of the preservative, and the duration of the treatment. Such tests in conjunction with fundamental research in wood structure should result in removing most of the present difficulties in the treatment of refractory species and of green wood, and should thus greatly increase the use of preservative treatment.

Many consumers like farmers necessarily use non-pressure treating processes because of their greater simplicity. More or less work has been done by several agricultural colleges and experiment stations and by the Forest Service on non-pressure processes for creosote, and work has begun with water soluble preservatives. Additional work will be required.

Service Tests of Treated Timber

The purpose of service tests of treated timber is to obtain comparative records on the effectiveness in actual service of the various preservatives and treatments for ties, poles, posts, mine timbers, and piling. If combined with similar tests of untreated materials, the advantage is obvious. A large number of installations of both treated and untreated experimental timbers under service conditions have been made by a long list of timber-using organizations like railroads and telephone companies in different parts of the United States during the past twenty years, independently and in cooperation with the Forest Service. The objectives in these tests have been mainly preservation against decay and marine borers. Gradually a comparative record of the greatest value is being built up, which must be continued for years to come because of the long life of some classes of treated timbers, the constant introduction of new preservatives and methods of treatment, and the increasing necessity to use species formerly regarded as worthless.

Paints and Waterproof Coatings

The effectiveness of paints and coatings depends upon the protective surface they form over the wood. This reduces the extent and rapidity of moisture changes and the consequent checking and weathering. Although a large amount of research has been done by the manufacturers on the composition of paint, no systematic study has ever been made of its quantitative value as a protection from weathering or of its influence on decay, or of the best paints and methods of painting for the different species of wood. This is significant in the light of the annual paint bill of the United States estimated at $300,000,000, about one-half of which is used on wood. A comprehensive exposure test has recently been started by a number of agencies in cooperation with the Forest Service. Progress probably hinges on knowledge of wood structure, of the chemistry of wood extractives, of the penetration of paint oils into wood, and

the adherence of paint films to wood. A paint of satisfactory appearance which can be used on wood impregnated with preservatives is badly needed.

As already stated, a large part of the trouble in the fabrication and use of wood arises out of shrinkage and swelling caused by moisture changes. Some progress has been made in reducing moisture changes by impervious coatings such as aluminum leaf. Investigations should be continued to find coatings of suitable character and durability which have higher moisture resistance than any now available, and if possible also, an absolutely moisture-proof coating.

PROTECTION FROM FIRE

The treatment of wood to make it fire resistant goes back to experiments with silicate of soda and other chemicals made in Europe as early as 1820. The competition of less inflammable building materials with wood, and the regulations established against the use of inflammable building materials in congested districts and in high buildings have accentuated the importance of developing some cheap and efficient process for making wood fire-resistant. The New York City Building Code provides, for example, that wood entering into the construction of buildings over 150 feet high must be rendered retardent by an approved method, or be covered with metal.

A large amount of commercial investigation has been attempted on this question. In a series of Forest Service tests all of the fire-retarding paints tested offered some protection. None of the coatings, however, made wood fire-resistant except to a limited degree. Other investigations have shown that injected chemicals can make wood so resistant that it will not carry flame. The cost, however, prevents extensive use. No means is yet known of rendering wood absolutely fireproof, but it is probable that further research might develop improved methods of treatment. Proper construction plays a big part in protecting wooden buildings from fire. Tests of various types of construction involving the use of wood as well as other materials are under way at the Bureau of Standards.

6. REQUIREMENTS AND SPECIFICATIONS

PROPERTIES ESSENTIAL TO DIFFERENT USES

As supplies of the commonly-used species decrease it is becoming more and more necessary to select substitutes. The substitution of a long list of species for white pine has for instance been going on for several decades throughout the East. Proper substitution first requires a knowledge of the properties of the unused species. But it requires equally a knowledge of the properties required to afford satisfactory service in the proposed use. It is helpful to know the properties of the species which afforded satisfaction. Because of the extreme variety of uses it is necessary to consider a very large number of combinations of physical and chemical properties to insure the highest degree of service. Investigations of this sort must also take into account changes in design, manufacturing processes, and costs made necessary by substitution. The field is actually much broader than that of enforced substitution. It should be possible to guide utilization for all purposes into the best channels so that

all woods shall be used for the purposes for which they are best adapted. Much progress has been made in the studies of the properties of various species, but with few exceptions there has been no study to correlate properties and uses. Work in this broad field is badly needed.

SPECIFICATIONS

Throughout the discussion of forest products research it has been necessary to refer repeatedly to specifications and grades. For many years we have had a large number of specifications, standards, or grades for lumber, paper, rosin, and other forest products and by-products. Until very recently, however, they had their foundation in the general knowledge of their product which men in the industries had slowly acquired. The history of all has been a series of evolutionary compromises, among manufacturers, distributors, and consumers. It is only during the last 15 years that the results of research have begun to appear in any pronounced way.

The most important forest products specifications are those for lumber, called lumber grades. Each important forest region has had its own distinct set of grades, and in a number of instances there were two or more distinct sets for a single species, so that nationally the situation has been very complicated and confusing. The Central Committee on Lumber Standards, representing producers, distributors, consumers, and technical men, has been working for several years with the Departments of Commerce and Agriculture to formulate uniform rules for all species and regions. Rules for softwood yard lumber recommended by the Forest Service have made the most progress. After having been scrutinized by the trade and modified to some extent they have been endorsed by the Central Committee, and are gradually being put into use by most of the major lumber associations. Recommended specifications for softwood factory lumber are now under consideration by the Committee, as are also similar recommendations on hardwood factory lumber. Scientific rules for structural timbers in which density was used as an indication of strength were adopted some years ago for southern pine by the lumber manufacturers' associations concerned and the American Society for Testing Materials; and for Douglas fir by the West Coast Lumbermen's Association. Modifications of these rules have been recommended in the light of subsequent experience and are now under consideration by the Central Committee.

General specifications for poles and for railroad ties are now under consideration by the American Engineering Standards Committee.

A somewhat different class of specifications is represented by a safety code for the construction, care, and use of ladders, which is now being prepared by the American Engineering Standards Committee. Numerous aeronautical specifications on the selection of woods, on kiln drying, on airplane parts such as propellers and wing beams, and on glues and gluing, have been prepared by the Forest Service in cooperation with the War and Navy Departments.

The building code presents a problem of exceptional difficulty. Practically every city of any size in the United States has its own distinct code. An important movement towards uniformity is represented by the

Building Code Committee of the Department of Commerce, which includes wide industrial and scientific representation and which has already recommended minimum requirements for small dwelling construction. These have been incorporated in whole or in part in the building codes of a number of cities.

Still another class of specifications has to do with wood preservation, of which those of the American Wood Preservers' Association are outstanding. For these Forest Service research has supplied a large part of the basic information. They include standards for preservatives, preservative processes, and treated material. A comprehensive set of paper specifications are now under preparation by the American Engineering Standards Committee. The Bureau of Chemistry has prepared a set of standards for rosin which are legal standards for the United States.

The preceding illustrates the present situation but is by no means a complete list. In general, specifications for forest products should be made a concrete expression of the results of research. They are of particular value to the general public and to industry. It is important that all specifications which are still on an empirical basis be given a scientific foundation. It is also important from every standpoint that provision be made for keeping specifications as nearly abreast of research progress as may be consistent with reasonable industrial stability. Altogether specifications offer an exceedingly effective means for putting the results of research into practical application.

7. UTILIZATION SURVEYS AND THE INTEGRATION OF INDUSTRIES

The preceding discussion has dealt with individual projects and relatively little with the relationship which each should bear to the entire utilization question of a particular region in order to be most effective. Something additional is needed, therefore, which will focus on the entire utilization problem of particular regions all of the knowledge which has been made available in all classes of forest products research. Local or regional surveys of forest, logging, manufacturing, and market conditions offer one such means. Possibly surveys of this character afford the only way of bringing out in their proper balance all the relationships and possibilities of better utilization.

One of the results to which such surveys may well lead is the determination of the technical feasibility under specific sets of conditions of groups of industries so integrated that they will use completely all the material which can and should be taken from the woods. For example, a sawmill might operate in conjunction with supplemental plants which would utilize material unsuitable for lumber for special products, possibly small dimension stock, and a pulp mill which would use all the remaining plant and woods waste including small and defective logs and even the branches. Such integration of forest industries, common in Europe, is beginning in several regions of the United States, and unquestionably constitutes one important key to our utilization and an effective means of reducing waste. Rightly used it can make possible the intensive practice of forestry. The movement toward integration can be greatly accelerated, however, if a foundation is established by research. The integra-

tion of industries has economic aspects also which will come up for consideration in the succeeding section.

Local or regional utilization surveys may in many cases derive advantages from experimental trial on specific forest areas such as the experimental-demonstration forests of Forest Experiment Stations. This affords an opportunity for combining in still another way silvical and utilization research. On such areas experimental silviculture and utilization may be tried out and practical utilization and silviculture demonstrated.

8. OUTSTANDING PROGRESS AND PROBLEMS

The outstanding progress to date in forest products investigations of a more fundamental character is in the determination of the strength properties of wood. Important but smaller progress has been made on the heat and moisture relationships which underlie the shrinking, checking, and working of wood and make seasoning and handling much more difficult.

On the side of applied or industrial investigations the greatest progress has been made in the development of better methods of kiln drying, of much more effective methods for preservative treatment, in large improvement in the design of boxes and containers and other structural units, in the determination of suitability for pulping under various processes of a large number of American tree species, in material improvement of glues and methods of gluing, and finally in the formulation of standard grades for lumber and for structural timbers. This with less conspicuous progress along many other lines represents a very substantial advance in our knowledge of wood and its behavior and how to use it effectively. The great bulk of the advance has come from research of the last ten years.

It is exceedingly difficult to limit to a few lines of work the important forest products problems of the future. One very large field, and practically the last which has not as yet been covered fairly well by preliminary research, is ways and means of improving utilization in those processes such as lumber manufacture and use which involve a large amount of cutting and recutting and where waste occurs in largest volume. A direct attack on logging and manufacturing processes and on the detailed requirements of all wood-using industries, including regional utilization studies and technical studies of the integration of industries, ought to yield large returns.

Among fundamental investigations, which constitute the great problems of the future, large emphasis ought to be placed upon wood structure and particularly its minute aspects; upon heat and water and other liquid relationships of wood; the so-called "working properties" which are now so obscure; and the fundamental chemical properties, upon which as yet so little relatively has been done. Work on the modification of properties for special purposes should perhaps be given somewhat less emphasis. Fundamental strength investigations of the future should be concentrated primarily upon second growth. Research on properties must be balanced by equally intensive research on the requirements of use. Much more work is needed on the fungi and insects which destroy wood.

In applied or industrial research the largest requirements of the future, aside from the waste problem already mentioned, are more intensive in-

vestigations than those of the past upon such questions as preservative materials and processes, the pulping of wood, the more difficult problems of design such as joints and fastenings, and finally upon specifications which will bring into practical application so large a part of all scientific results.

American research on the properties and utilization of wood and other forest products, and that on forest management, are gradually converging. The number of problems which require the direct cooperation between the two classes of investigators is gradually increasing. The boundary between the two classes is becoming more and more indistinct. Forest products research requires as the most essential condition to its effectiveness in the broad sense of the word the closest possible relation to the growing forest and to forest management.

FOREST ECONOMICS

The primary purpose of research in forest economics is to afford a satisfactory basis for a sound forest policy for the entire United States, for its political subdivisions, and for its forest regions. The purpose is equally to afford a basis for the forest policy of forest industries and of private owners. Economic facts will for one thing indicate the unfortunate effects of non-use of forest lands and of timber shortages. These and other facts will also indicate remedies. They should indicate clearly the proper place, including both opportunities and obligations, for public and private agencies in the general forestry structure. They should indicate on one hand the restrictions, if any, which the public should impose on private owners, and on the other hand, the aid which in justice the public should return. Unless the necessary economic facts on requirements and potential growth are available, we cannot be sure of balancing our timber budget for our entire national requirements and for each important class of products.

Research in forest economics should perform another invaluable service in furnishing a background for all other classes of research. It should in many cases point out the problems which are most acute and urgent. In short, it should supplement and round out and in a sense underlie the general forest research structure as much as it should that of forest policy.

Forest economics has been classified for the purposes of this report under such topics as forest land, timber, manufacture and distribution, and prices. Investigations under these topics, however, will have to collect, compile, and analyze data by political, natural, or industrial subdivisions such as the country as a whole, forest regions, States, and possibly also by minor political subdivisions. Data will also have to be considered by industries in their entirety, by regional groups within industries, and by individual concerns. This secondary classification cuts across the first in many cases and should therefore be kept in mind for a full understanding of the scope of the program of economic research outlined.

1. FOREST LAND

The term forest land is used for the land proper and for the broad economic or social service it can render. Timber and other products,

although economically a part of the land, are discussed separately for convenience.

Economic Significance of Use and Non-Use of Forest Land

Attempts to determine concretely the economic significance of the use or non-use of forest land in the United States are very few and recent. Except for meager information from a few localities and regions resulting mostly from investigations of the Bureau of Agricultural Economics in cooperation with the State Universities of Michigan, Minnesota, and Wisconsin, and of the Forest Service, we still have ahead the task of learning specifically what it will mean to have a timber-growing industry comparable with agriculture in its use of land. While we may appreciate in general terms its significance, we have still to learn concretely the value of stable and permanent timber-growing industries, what such industries mean in adequate transportation, the contribution of timber-growing and wood-using industries in taxes, the economic value of prosperous, self-supporting, stable, and permanent communities.

We know a little more of the reverse—the adverse economic effects of non-use or of idle forest land as measured in transient industries, discontinued transportation, low tax-paying capacity of both land and industries, transient and decaying communities, and deserted towns. This is the result of an intensive study by the Forest Service.

Diversified agriculture has been much in the foreground recently as one means of insuring the farmer against loss from overproduction and low prices of farm crops. But the real significance and possibilities of the farm woodlot as a factor in diversified agriculture, as a specific example of the service of forest land, are known only in the most general terms. We know, for example, that timber values as measured by stumpage prices have not fallen off appreciably, or at all, or have actually risen during the past few years of low prices for agricultural products in general. There have been only a few local exceptions to this general rise.

Social Significance of Use and Non-Use

Economic prosperity and decadence are closely related to social conditions. As a basis for sound policy and incidentally to arouse the public to the full significance of what is going on in many sections of the country, we ought to know as concretely as possible what it means locally, for example, in social welfare, in the distribution of population, in schools, hospitals, and standards of living, and what it means nationally in a numerically strong and physically stalwart, forest-bred and forest-living race, to maintain forest lands in production or allow them to become idle. The barest beginning of work in this direction has shown results significant enough to justify thorough investigation at the earliest possible date.

Ownership

The extent and character of the service which forest land may render depends in part upon whether ownership is public or private. This is partly because the exceptionally long period required to mature timber crops makes public ownership more feasible than private under some conditions. This may be true where large-sized products are concerned or those of special quality which require long periods for growth, where the

land is of poor quality and low productivity, or where indirect benefits such as stream control outweigh the direct returns from timber growing and hence dictate unprofitable silviculture. It is conceivable that eventually the public may have to choose between large public ownership of forest land and a certain degree of aid in fire protection and adjusted taxation, or a certain degree of public regulation of privately-owned lands, or a combination of aid and regulation, in order to insure supplies of timber ample for public requirements. Where should the line be drawn? Then there is the question of concentration of ownership. Within what limits may it be beneficial? Is it or can it become serious? What size of holding is best adapted to profitable private forestry under various conditions? To what extent should the manufacturer of forest products own forest land and grow his own timber? Such questions make necessary comprehensive investigations of the character and present distribution of ownership, its effects, the trends, how they should be modified for reasonable profits to private owners and for the general public welfare.

The Bureau of Corporations made a comprehensive investigation of forest land ownership about twenty years ago, primarily with reference to the bearing upon the public welfare of the concentration in a few corporations of the remaining stands of virgin timber, but with little bearing upon the problem of timber growing. Little in the way of analysis has been attempted since, although the Internal Revenue Bureau in the U. S. Department of the Treasury has collected a large amount of data with tax returns. In periodic agricultural censuses the Bureau of the Census also collects and publishes data on the forest land areas in farms.

Classification

Sooner or later we shall have to classify the land of the United States on the basis of its relative value for agriculture, timber growing, recreation, and other purposes. Or we can drift and permit land classification to be worked out by the costly, time-consuming process of trial and error. Among other things we need to know as soon as possible by States, regionally and nationally, is just how much land by classes of productivity is likely to be available in the future for timber growing, and whether there is forest land enough to grow the timber needed to balance our timber budget. The distribution of this land with reference to population and hence to requirements is almost as important as its quantity and potential productivity. The prime service of land classification is to correlate different uses with both the acreage suitable to each and the needs for the product of each, or, in other words, to obtain a balanced land use. Classification is as important for agriculture as it is for forestry. The fundamental basis for a sound classification often involves problems of the greatest difficulty. Some land classification has been attempted in a very general way in a few States and most intensively and under the most comprehensive plan in Michigan, but the task in general lies almost entirely ahead. It is of first magnitude.

2. TIMBER

Available Supplies

Up to the present the people of the United States have concerned themselves primarily with existing amounts of timber and the rate at

which it could be cut. A great deal of work has been done by both private and public agencies to determine the amount of standing timber, its kind, quality, and distribution. With few exceptions, however, cruises or surveys of this kind have been local, covering only the holdings of a single owner and made under different plans and varying degrees of intensiveness for different standards of utilization by men of widely varying qualifications. State, regional, or national surveys or estimates of supplies have consisted almost entirely of compiling the results of these extremely variable local cruises. The time is fast approaching, however, if it is not altogether here, when the public interest will insistently demand fairly close knowledge of what timber we have left as a detailed basis for both public and private action. This information must be detailed enough as to kinds, quality, and distribution of timber and similar factors to supply all of the demands which will be made upon it.

Requirements and Cut

American timber requirements and the actual cut have heretofore been practically synonymous, but the time will come, as our population grows and existing supplies of timber are exhausted, when the gap between requirements and cut will be vary large. Furthermore, there is a large difference between the total drain upon the forest and the volume of material which goes into use which is made up in part of unavoidable, in part of largely avoidable manufacturing waste, and in part of similar losses from decay, insect attack, and fire.

Through Bureau of the Census reports covering many years and a much smaller number by the Bureau of Chemistry and the Forest Service we have a reasonably satisfactory knowledge of the annual production and trends of production of lumber and most other products from our forests. For some such products as fuelwood, however, which is responsible for approximately one-half of the annual cut of all products, information is fragmentary and unsatisfactory. It would be invaluable if censuses could be so arranged hereafter that the entire cut of forest products for all purposes could be covered periodically.

Of the total drain upon the forest we know much less than of the material which is cut. This is because very unsatisfactory data are available on losses from fire, insects, and disease, although various bureaus of the Department of Agriculture, independently and in cooperation with other agencies, have compiled the best data possible with the resources at their command. Information by quality as well as quantity on requirements, cut, the drain on the forests from all sources, and nationally, regionally, and by industries, is necessary for contrast with available supplies, new growth, and other possible means of meeting our needs.

Concerning the requirements of a large group of industries two or three steps removed from the forest, for lumber, pulp, or other forest products of primary or direct manufacture, we know practically nothing. Examples of this group are shook boxes made from lumber, fiber boxes made in part from pulp, and fiber silk also made in part from pulp. Concerning the output of these secondary or tertiary industries we know

as little. Censuses have so far collected values only for the requirements of raw materials and for the output of these industries. The time has come, however, in the evolution of our forest situation when data on quantities of both requirements and output are badly needed for a full understanding of public needs and industrial developments in relation to timber supplies and timber growing.

With an impending national deficit in production as compared with demand for forest products, there is ample public justification for intelligent effort based upon economic research to guide the demand along beneficial lines. The unguided operation of supply and demand does not always result in the most beneficial consumption.

This is already well recognized in research aimed at the substitution of relatively abundant and intrinsically valuable but little-used tree species for species which are scarce and in heavy demand; at the substitution of fast-growing species for those of slow growth; and at the substitution of low lumber grades for high grades in uses for which high grades are demanded by custom and prejudice rather than by necessity.

The same principle can and probably should be carried further by economic studies to show the feasibility of eliminating or reducing consumption which appears to serve no useful purpose and diverts forest products from beneficial use.

Another promising phase in the requirement field for economic studies in guiding consumption, is the reclamation and re-use of forest products. Reclamation and re-use of discarded papers is already being widely practiced. Re-use of newsprint by de-inking has been demonstrated experimentally. Lumber is being re-used in house construction to a certain extent. Re-use of boxes and containers is reported as a large business in several large cities.

The impending national deficit of forest products emphasizes also the importance of a better understanding of the economics of the waste of forest products in manufacture and by fire, insects, and disease. Investigations must start with the volume and character of these different classes of waste, and if their economic significance can be worked out in detail it will unquestionably stimulate enormously and make much more pointed and effective all efforts toward prevention and use. Much of the present inertia is undoubtedly the result of the absence of knowledge of this character.

The broadest possible understanding of our present and probable future requirements for timber and other forest products is one of the keys of our entire forestry situation. Such an understanding is in fact a determination of the place of wood in our civilization. It indicates the total amount of timber and other products that we ought to grow if the productivity of our forest lands permits. To be of greatest value, future requirements must be analyzed in the light of the utility or property requirements for different uses, the utility of different species of woods for these purposes, and how woods compare for these purposes with other and competing materials. Finally, there will be the question of prices which, other things being nearly equal, may be the deciding factor as to which of two or more competing materials will be used. Along with an understanding of total requirements will be necessary a knowledge of

the items for different purposes of which the total is made up. A thoroughgoing understanding of requirements becomes, therefore, one of the two essential facts for the balancing of our future timber budget. The second is growth.

New Growth

Two or three attempts have been made by the Forest Service to approximate the amount of current and potential timber growth for the entire United States, but have necessarily been based on rather fragmentary and unsatisfactory data. It is probable that these estimates are closer to actualities for the country as a whole than they can be for small subdivisions or for the requirements of special industries or products. Much more complete and accurate knowledge of both current and potential productivity is essential to a real appreciation of our timber situation and to the possibilities of meeting it satisfactorily. The critical relationship between potential growth and requirements and our timber budget is indicated in the preceding paragraph.

Substitution

The substitution of other materials for forest products is a means frequently suggested to meet our timber needs. Substitution for lumber has from time to time received more or less attention by the lumber industry. One fairly comprehensive study of the entire situation was made several years ago by the Forest Service, but current changes should be followed if we are to approach the whole question of timber supply most effectively. Investigations of substitution become for the forester the study of an important factor affecting timber requirements and the potential markets for the products of forest land.

Imports and Exports

The Bureau of Foreign and Domestic Commerce has for many years supplied information on American imports and exports of timber and its products. These have been analyzed with reference to our general and detailed national needs. Potential imports based on what is known of the resources of other countries have been similarly analyzed by the Forest Service, as one phase of a very comprehensive treatise on the forest resources of the world. The whole question, however, is one that should receive fairly continuous consideration, particularly as better data on foreign supplies become available and on the possibilities of enlarged or reduced importations. More and more the question of timber supply is becoming a world question, and American problems cannot be considered alone even though there can be little hope of meeting any substantial part of our needs from foreign timber.

Economic and Social Effects of Timber Shortages

Because of the enormous volume of stored timber in the United States which has supplied our needs lavishly until almost the last decade, pronounced economic and social effects of timber shortages are only beginning. We should, however, have current information on the adverse effects of shortages so that we may better measure their present and ulti-

mate effects and hence the effort which we as a people are justified in making to meet our full requirements.

3. FOREST SURVEY

The balancing of available timber supplies, imports, substitution, and growth on the one hand, with requirements, cut, drain upon the forests, and exports on the other, can only be possible in a thoroughly satisfactory way when based upon detailed, authentic information. The collection of such data with study of related land questions such as area available, its distribution, and quality (a rough land classification, in short), and the extent to which it is now productive, constitute what has been called a forest or timber survey. The forest survey idea brings together under one head and coordinates many of the economic investigations of both land and timber previously proposed. The forest survey affords the means of orienting forests, forest lands, forest influences, and forest products in the entire economic and social structure of the country.

To meet this need nationally we have the Bureau of the Census and the Bureau of Foreign and Domestic Commerce reports on cut, imports, and exports, and that of the Bureau of Corporations on timber supplies and forest land ownership already mentioned. We have also two Forest Service reports which bring together the best information available on the whole question for the entire country. In short, we have enough information now to make the general phases of the situation known, and to justify prompt action on such important questions as fire protection, better utilization, and bringing all forest land into productivity at the earliest possible date. But until we have a national survey we shall be seriously handicapped in formulating and carrying out fully satisfactory forest policies, particularly in detail.

A national forest survey is a task of great magnitude, of infinite detail, a truly national undertaking. It would require several years for completion, and properly done its cost would aggregate several millions of dollars. It would necessitate the cooperation of a large number of agencies, public and private, preferably under centralized Federal leadership.

Meanwhile there is every reason why partial surveys should go forward. They can cover either distinct regions, or States, or specific industries. For maximum benefit, local or regional surveys should include all the relations of forest lands, forests, forest influences, and forest products to economic and social development in both agriculture and industry. But surveys that cover any essential part or parts of the whole are of a distinct value. Much of the work which has been done so far is in fact of this regional, or State, or industry class, as is also everything which is now being attempted.

We have a series of studies of the requirements of the wood-using industries in practically all of the States with any timber, made mostly by the Forest Service in cooperation with the States. The later studies of this class have been including more and more the relationship between wood requirements and existing stands of timber, and the potential timber growing capacity of the forest lands. We have some scattered attempts at land classification, primarily the activities of individual States.

The Forest Service has made an inquiry into the national pulpwood situation, which has been followed by somewhat similar surveys by the American Paper and Pulp Association. The Southern Pine Association has made two studies of the lumber situation in its territory. In general, local studies so far made and those under way are very fragmentary, considering our national needs.

4. MANUFACTURE AND DISTRIBUTION

BUSINESS ECONOMICS

Separate forest industries and individual companies, those which cut or manufacture forest products, face a group of problems which fall more or less clearly under the designation of business economics. The group includes costs, returns, and finance in general, markets and marketing, competitive conditions, and the economic side of such questions as operating efficiency, utilization, and waste. A proper understanding of the group of business economic problems indicated, which would obviously have to be based upon research, should carry these industries into channels which would be beneficial to the general public in addition to the industries themselves. Phases of this question touch closely upon forest finance, which is taken up later.

Then there are broad questions of the place of the forest industries singly and in the aggregate, in the whole industrial and economic structure of the country, which from every standpoint ought to be better understood. This general idea is touched upon elsewhere, but it should be crystallized here. It involves relationships between forest and non-forest industries, in some cases very obscure in the light of our present knowledge, but vital to both and to the general public. For example, a change in style of women's clothing is said to have modified radically the requirements for dress fabrics, and finally, through a chain of causes to have affected seriously the demand for some of the products of the wood-turning industry. This sort of consequence could not be anticipated, but others of equal or greater importance could if we had better information. Much more predictable would be the interrelationships between the forest industries and the railroads, water transportation, and agriculture.

The technical problems involved in the integration of wood-using industries have already been outlined. The economic possibility, however, of combining advantageously groups of lumber, pulp and paper, and other manufacturing plants which will use different parts of the forest product and hence make an important contribution to the reduction of waste, calls for a different but closely-related class of data. The limited number of examples of integration of this sort in the United States might be materially increased by intensive study of the economic advantages and future attempts guided into the most effective channels.

Studies of operating efficiency to get at underlying principles as a basis for the best plans of logging or other operations have been made by the Yale Forest School, the Harvard Forest School, and by the Forest Service. Yale has also worked on other phases of the business economics

of the lumber industry. The Forest Service has made one thoroughgoing study of the business economics of the lumber industry.

DISTRIBUTION

Not least in importance among the aspects of the distribution of forest products is the relation of the cost of distribution to the stumpage price of timber on the one hand and to the wholesale and retail prices of the manufactured products, such as lumber, on the other. A thorough understanding of these relationships is therefore a vital matter to the grower of timber in an understanding of potential profits as well as to the consumer who pays for the final product. From the standpoint of the general public it is only through a knowledge of what unnecessarily long distance hauls really mean in higher direct and indirect costs that full appreciation will be gained of the advantages and opportunities of growing timber locally and reducing to the utmost the length and hence the cost of hauls. For example, it now costs $25 or more to haul lumber by rail from Portland, Ore., to New York City, practically as much as to manufacture it, and this cost may be doubled or trebled to the ultimate consumer of the lumber to take care of profits and other distribution costs.

Transportation costs have also a definite relation to better utilization, rather obvious in its general aspects, but which still remains to be worked out in detail. More low-grade material can be taken from the woods and manufactured for nearby than for distant markets. To what extent classification of lumber for rate making, with lower freight rates applicable to the cheaper grades, would be justified by the increased tonnage developed and possibility of closer utilization in the woods, is a problem for investigation. There is a further relationship, now but little appreciated, but which can probably be developed satisfactorily only from concrete facts, between localized and distant supplies and the number and size of local industries. Small industrial establishments are undoubtedly a corollary of local timber, but soon succumb to the competition of large plants when raw materials must be brought from distant sources. This relationship goes very far into the basic structure of the forest industries and should be better understood.

The preceding paragraphs illustrate in part the research needed on the vital question of distribution. They may be examples which are peculiar to the forest industries and do not in themselves offer more than a partial solution of a much broader distribution problem affecting all materials and commodities which adds so greatly to the cost of living in the United States at the present time. There are undoubtedly, therefore, many additional phases of the distribution problem which should be subjected to most intensive study paralleling those which are conducted by other agencies on other materials.

Except for fairly comprehensive studies by the Forest Service and trade associations of wholesale and retail lumber distribution and of the volume of the lumber which goes to different States and regions, and those on the relation between stumpage and lumber prices and transporta-

tion costs made or now under way by the Forest Service, little work has yet been done on the distribution of forest products.

5. PRICES

Prices of various kinds, on standing timber or stumpage as the first product of the forest, on logs, on lumber at the mill and at wholesale and retail, and on some final products, have frequently been referred to as subjects requiring investigation. It seems advisable, however, for clarity to bring together for discussion under one head the entire price relationship. Both the public and the industries need to understand the underlying laws governing changes and trends in prices, which are now known only in the vaguest way. We need to know the relation to prices of a large number of economic and social factors, and vice versa, as a basis for an intelligent public forest policy. The need of private concerns for such information is as great.

The Yale Forest School has been studying lumber prices for a number of years. The Forest Service has also done some work along this line and is now collecting in cooperation with the Bureau of the Census, and analyzing, a very comprehensive set of stumpage price data from all parts of the United States. In general, however, relatively little has been or is now being attempted beyond the collection and publication by a number of industrial and public agencies of a small part of the data which would be necessary for a thoroughgoing fundamental study of price relationships.

The tariff question is closely related to that of prices and can logically be mentioned here. Until the creation of the Tariff Commission, which now makes necessary inquiries, the investigations which were regarded as necessary for tariff charges were made by Congressional Committees. Several of these investigations, as, for example, that on lumber in 1902 and that on pulp and paper in 1908, contain a mass of valuable statistical material.

6. OTHER PRODUCTS AND INFLUENCES

For some of the products of the forest, such as forage upon which a part of the grazing industry depends, there is an economic field requiring investigation similar in its broader outlines to that indicated for timber products. Information is needed on such questions as the economics of range management, or ranch organization, the costs of livestock production including taxation, the most satisfactory type and age of animal from the financial standpoint, and on the marketing of products. On such questions exhaustive reports by the Tariff Commission on wool production and production costs, etc., of beef cattle are available. The economics of the range livestock industry in general has also been studied at various times by the Forest Service, the Bureau of Agricultural Economics, the Bureau of Animal Industry, the State agricultural colleges, and private organizations. There is need, however, for an exhaustive study of the situation in representative regions.

The indirect influences of the forest such as streamflow and soil fixation, and such uses as recreation, have important economic aspects which

should be understood but on which as yet little or nothing has been attempted.

7. TAXATION

Forest taxation is an important element in the cost of timber growing. As much or more from its future uncertainty as from its current amount it is commonly alleged to have had a more or less serious effect in retarding timber growing on private lands. The non-existence of a timber-growing industry until very recently, the lack of public understanding of its nature, the great difference between timber growing and nearly all other forms of taxable enterprise, and the involved nature of taxation questions in general and forest taxation in particular, combine to emphasize the importance of research. While logically a part of forest finance, taxation is so distinctive that it is taken up separately.

With the exception of work in a few States, notably New York and Wisconsin, by the National Institute of Public Administration and the National Industrial Conference Board, respectively, and an investigation in New Hampshire and Wisconsin by the Forest Service, practically all of the consideration heretofore given to this vital question has dealt with the theory and has been handicapped by a deplorable lack of basic facts. Considerable work has been done, however, on the theory of forest taxation by the Forest Service, special forest tax committees, the Michigan Agricultural College, and other agencies.

Research of forest taxation must first obtain data to show in detail the existing forest land and timber tax situation and in more general terms the tax situation on other kinds of property. It must give information on the place of forest taxation in local revenue. It must include detailed information on the constitutional, legislative, and traditional bases for taxation and their practical application in the levying of assessments and collection of taxes on forest land and other classes of property.

A second important class of information is needed to show the effect of the current tax situation on reforestation and timber growing. This should include such information as the land policy of timberland owners, the plan which they follow in the cutting of their mature forest, what is being done in protection, and efforts made in reforestation.

Other information required includes that necessary to work out and to check modified systems of taxation. It should include for the various States studied constitutional, legislative, administrative, and traditional restrictions and handicaps which have a very large practical value in determining both the form and extent of feasible modifications. It must include information on such phases of public opinion on taxation and sources of local revenue as are likely to influence the character and extent of modifications.

It should include also information on the systems of taxation in effect in foreign countries and in each case their broad relation to the general taxation system. Finally, the place of taxation as an element in the cost of production and forest finance in the whole timber-growing problem must be properly understood.

Conditions in the woods, in State constitutions and legislation, in traditional procedure, and in public opinion differ so widely in different

States and parts of the country that investigations in forest taxation will undoubtedly have to be nation-wide. A study of this general character has recently been undertaken by the Forest Service in cooperation with a large number of agencies. One result of taxation studies should be the development of ideal systems for different conditions, systems which on the one hand will make the growing of timber a feasible business enterprise and on the other provide an equitable share of the local and State revenue. But progress towards ideal systems may have to take place slowly by a series of advances and compromises over a long series of years. Changes in general taxation systems will moreover necessitate corresponding adaptations in forest taxation, and the whole situation is so complex that satisfactory solution under present or future conditions will have to depend upon present and long-continued collection and analysis of economic facts.

8. FOREST FINANCE

In addition to forest taxation, the business of growing forests includes several groups of problems which may perhaps be best described under the heading of forest finance, problems many of which can be answered satisfactorily only through economic research.

The financial feasibility of timber growing is one of the most important of these groups. The national timber budget cannot be balanced without private forestry. Only approximately 21 per cent of our forest land is in public ownership, and much of the best is privately owned. Private forestry depends on profits. Experience has shown that the point at which private forestry becomes profitable is not anticipated by private land owners and seized upon as soon as it arrives. On the contrary, the two big forestry developments of recent years in the southern pine and redwood regions were discovered by private owners after their feasibility had existed for some time. The same is true of the older development in the New England pine region. The reason is that some of the factors bearing on profits are so complex or involve simultaneous observations in such wide fields that the individual owner does not keep currently posted. An important part of research in forest economics is, therefore, to discover possibilities for private forestry and to collect the experience of the entire country and focus it upon local conditions.

Some enterprises will start with planting on the bare land, others will start with partly-grown timber. Most cases, however, involve the financial feasibility of converting going concerns now operating on virgin timber to a perpetual basis through growing their own timber. These are concerns which would otherwise cut out and discontinue operations within a relatively limited period. In more detail, this group of problems must, therefore, include the cost of timber growing, a subject on which, badly as it is needed, practically no comprehensive information has been made available in the United States today. There are other involved questions also of land valuation, credits, and interest. Forest insurance is a special cost item in itself upon which in the United States practically nothing has been done. Another cost item of forest taxation has already been discussed. Gross returns are well indicated possibly by the stumpage price of the standing timber when ready for sale or cutting, and thorough in-

vestigation of stumpage values and trends has only begun. The conversion to a permanent basis of going but temporary operations referred to above introduces new complexities. It is in effect the determination of the relative financial advantages of amortization and sustained operation. All of these factors, including also net profits, are of vital concern to the land owner who is considering the advisability of growing timber. They are also of vital importance to the general public because misinformation concerning actual conditions may discourage private initiative whereas a knowledge of the facts would stimulate private effort.

The preceding paragraph relates to the costs of timber growing as they may exist, but there is a distinct possibility of reducing costs by greater efficiency to a minimum per unit volume of timber raised. Where it seems advisable to increase costs in order to increase the quantity or quality of yields, there is the possibility of determining the point of diminishing returns. Such specific questions as the following are involved: forms of organization, systems of administration, the distribution of men, the size of the most effective units of administration, standards of intensity of work, and the location of improvements such as roads, trails, and telephone lines, with reference to resources and the amount of work to be conducted. It is practically impossible to reach an intelligent decision on how much should be spent on fire control until through research the expenditure per acre which will give the maximum net returns of the kind desired is ascertained. And it may be found that even this is not the entire story but that other larger and more intangible factors have to be taken into account, at least in public forestry. Efficiency and costs of fire control can thereby be related to silviculture and the productivity of the forest. These are intricate problems and there is no substitute for knowledge as a foundation for sound theory and practice.

A third group of problems closely related to forest finance even though possibly not entirely a part of it, come under the general term of forest regulation. This group, in fact, through its study of the kinds of timber which should be raised for highest profit, the sizes which should be produced and under what length of rotation, relates the entire question of financial policy back to the underlying silviculture and forest management. Undoubtedly many problems falling under this head are largely administrative in character, but many of them can best be solved through research methods.

9. OUTSTANDING PROGRESS AND PROBLEMS

In forest economics the greatest progress in research has been made upon the factors which make up a forest survey, including timber supplies, the cut for various purposes, actual and potential replacement by growth, the effect of substitution, and the area of forest land. A large amount of data has been collected on prices of lumber and of standing timber, which as yet have been only partially analyzed. One comprehensive investigation has been made of forest land ownership and a beginning has been made upon special phases of the distribution problem. Most of the rest of the work is fragmentary and incomplete.

Much of the most significant work done in forest economics has been the reanalysis of statistical data collected for other purposes. Such anal-

ysis has been carried far enough, in fact, to be a guide to public and industrial policy in its broader outlines. Even with obvious limitations the findings have already had an important influence in molding public opinion. Fairly satisfactory and more or less concrete statements have taken the place of the generalities with which for many years the public had to deal. It is known, in short, that action is required on our forestry problem and that action must be taken along specified broad lines.

The greatest, most insistent, and by far the most complex economic problem of the future is a comprehensive and detailed forest survey for the entire country, an enormous task which would require a large expenditure of money and the efforts of many different organizations. A survey should include many phases of first importance, some of which might be handled separately, such as an investigation of our present and probable future timber requirements in the light of industrial trends, substitution, and many other factors. If a broad national survey cannot be undertaken immediately, regional, State, or industrial surveys would be of great value and might easily be made to include all of the economic conditions which should be taken into account in a full understanding of the forestry situation and as a basis for forest policies.

Hardly less important is the need for comprehensive information on the financial feasibility of timber growing, particularly by private owners. This is a project of many ramifications, which includes such difficult and specialized problems as that of forest taxation. The problem of distribution, viewed from a broad standpoint of the entire mechanism involved in the handling and transportation of lumber and other forest products from the factory to the consumer is vital to both the forest land owner and the consumer of forest products, and ought to receive a large amount of attention. It is difficult to pass without especial emphasis the economic and social significance of forest land use and non-use, and of adequate timber supplies and shortages. Many other problems in forest economics should have attention, but possibly not in the same measure.

THE RESEARCH AGENCIES IN A NATIONAL PROGRAM

The number of organizations that are undertaking more or less forest research is already large and includes several bureaus each of the Federal Departments of Agriculture and Commerce, as well as a number of other Federal organizations. In many States the list includes several agencies such as the State universities, the agricultural colleges and experiment stations, and the executive departments. It includes endowed universities and research institutions, industrial associations, corporations, and individual owners of forest land and manufacturing plants.

The discussion of the research problems in a national program and of progress in their solution gives only a partial basis for sound judgment on the extent to which agencies already doing forest research need to be enlarged and other existing organizations should be interested and new agencies created. As an additional basis for such a judgment it will be helpful to consider in detail what forest research organizations are already in existence, what in general terms they have done or are doing, and what they can best undertake.

Hard and fast lines cannot be drawn between the work which Federal, State, endowed, private, and other organizations can best undertake. Some generalizations are possible, however, which indicate some of the more obvious facilities and handicaps of various agencies for the handling of forest research; but even these generalizations must be subject to modification because of the exigencies of appropriations or endowments, personnel, work already under way, and other similar factors. It is much more important that the work be done, than that it be done by any specific agency or agencies.

EXISTING AGENCIES AND THEIR WORK

1. UNITED STATES DEPARTMENT OF AGRICULTURE

Investigations in different bureaus of the Department of Agriculture cover all of the major classes of forest research which have been discussed—forest management, forest protection, forest influences, forest range management, wild life, the utilization of forest products, and forest economics. As might be expected, the greater part of these activities are conducted by the Forest Service, within which all investigative work is concentrated in a Branch of Research.

Research in forest management and forest protection is centered primarily at a series of forest experiment stations, some of which are maintained by two or more bureaus in cooperation and others by single bureaus.

FEDERAL FOREST EXPERIMENT STATIONS

At the Federal Forest Experiment Stations the Forest Service is responsible for investigations in forest management and protection against fire. Forest pathology is assigned to the Bureau of Plant Industry, while forest entomology falls under the Bureau of Entomology. Relatively

small amounts of research on special phases of forest management have from time to time been conducted also by the Bureau of Soils, the Weather Bureau, and the Biological Survey, respectively.

The Forest Service

Research within the Forest Service mostly of a somewhat general character antedated by many years the establishment of the first forest experiment station in the Southwest in 1908. Since 1920 the Forest Service has been developing a series of regional experiment stations in pursuance of a national program, announced in Departmental Circular 183, "Forest Experiment Stations," of an adequately manned and equipped station in each of the 10 or 11 important forest regions of the United States. The underlying conception has been that each station would work on problems of a region of similar forest conditions, as, for example, that of the Lake States where a group of forest types characterized mostly by the predominance of white, Norway, and jack pine and of the northern hardwoods—birch, beech, maple, and aspen—extends over much of Michigan, Wisconsin, and Minnesota. The organization of each station consists of a central headquarters, preferably with university contact, from which the permanent technical staff works out as necessary to a series of field branches or experimental and demonstration forests representative of important subregions.

The investigative staff consists first of a nucleus of foresters, with advanced training wherever possible in some phase of forestry, or some basic science such as physiology, ecology, soil science, or genetics. Gradually, however, the extreme diversity as well as the ultimate unity of the timber growing problem has been realized and the need for fully rounded-out forest research centers has gained recognition. Cooperative plans are well advanced, therefore, under which the Bureaus of Plant Industry and Entomology, respectively, are assigning forest pathologists and entomologists to the stations and may in the future be carried still further by the addition of zoologists and other specialists. Anything approaching the realization of this general conception will mean the many-sided attack on the problems of timber growing and protection which their real nature demands.

The following progress has been made on the regional forest experiment station plan:

Northeastern Station, covering the New England States and New York, established in 1923, investigative staff 5 men, allotment approximately $27,500, headquarters maintained in cooperation with Massachusetts Agricultural College.

Appalachian Station, covering the Appalachian territory south of Maryland and Ohio, into northern Georgia and Alabama, and as a matter of administrative convenience the Piedmont and Coastal Plain of North Carolina, Virginia, and Maryland, to the Atlantic coast, established in 1921, investigative staff 7 men, allotment about $37,500.

Southern Station, the pine and hardwood territory along the Atlantic and the Gulf of Mexico from South Carolina to Texas, inclusive, and Arkansas and Oklahoma, established in 1921, investigative staff 7 men, allotment about $39,000.

Lake States Station, covering Minnesota, Wisconsin, and Michigan,

established in 1923, investigative staff 5 men, allotment approximately $26,500, headquarters maintained in cooperation with the University of Minnesota.

Northern Rocky Mountain Station, covering Montana and northern Idaho, established in 1911, investigative staff 5 men, allotment approximately $21,000.

Rocky Mountain Station, covering forests of Wyoming, Colorado, Nebraska, and South Dakota, established in 1909, because of reduction in appropriations reduced in 1921 to the present investigative staff of 2 men, allotment about $12,500.

Southwestern Station, covering the forests of Arizona and New Mexico, established in 1908, because of reduction in appropriation reduced in 1921 to the present investigative staff of 2 men, allotment about $12,000.

California Station, covering the forests of California and western Nevada, established in 1912 and discontinued in 1917 because of reduction in appropriation, reestablished in 1926 with a staff of 6 men, allotment about $32,000, headquarters maintained in cooperation with the University of California.

Pacific Northwest Station, covering the forests of Washington and Oregon, central Idaho, and southeastern Alaska, established in 1912 and enlarged in 1924 to an investigative staff of 6 men with an allotment of $27,500.

Ohio-Mississippi Valley Station, to cover the forests of Ohio, Indiana, Illinois, Iowa, Missouri, and western Kentucky and Tennessee. Bill authorizing its creation was passed by Congress in 1926.

Middle Atlantic Station, to cover the forests of Pennsylvania, New Jersey, Delaware, and Maryland. Bill authorizing its creation was passed by Congress in 1926.

The creation of the Middle Atlantic and Ohio-Mississippi Valley stations, in regions in which the Federal Government is now doing no research, will bring the total number to 11 and complete the series for the continental United States as now planned by the Department, although all the stations so far have small initial appropriations only. The Southwestern and Rocky Mountain stations particularly are operating on a very small scale. As the work develops it may call for adjustments in the territories as outlined and possibly even the subdivision of extended territories such as that of the Southern Station. Outside of the Continental United States, it may in time be advisable to establish a tropical station in the West Indies, for example, in Porto Rico. Eventually a station will also be required for Alaska. The year-long investigative staff in the Forest Service for research in forest management and protection from fire now totals about 50 men, including those with headquarters at Washington. Total funds available aggregate approximately $285,000.

In general terms the regional Forest Experiment Stations have covered or now have work under way in the following fields: Fairly comprehensive investigations on artificial forestation for western species, with a relatively small volume of work now under way, and a negligible amount of work on eastern species; a large amount of experimentation on silvicultural methods of cutting in about 14 of the most important forest types, and on factors affecting natural reproduction in about 18 important types; a reasonable amount of work on volume tables; the most comprehensive

investigations of growth and yields in half a dozen of the most important forest types that have ever been undertaken in the United States, and much less comprehensive investigations on as many more; two or three intensive investigations of forest influences, one of which is still under way; a fair beginning in research on forest fires with work in process in seven of the most critical forest regions and on a smaller scale in others; the dendrology of all American forest trees with the more intensive work of the past on the western species, and a beginning of similar intensive work on the oaks of the South; a relatively small amount of inquiry on life processes and structure; a share of the very meager work done on forest soils; several rather intensive ecological studies of climate and forest types, only one of which is now under way; a part of the work done on the life histories of trees and less on those of forest types, with work now under way on six trees and seven types.

Although a part of the research of the Forest Service, such as that on forest influences and that on the relation of climatic factors to forest types, is as intensive as any undertaken by any other organization in the United States or in any other country, most of the work so far done and that still under way is of a preliminary type leading to specific application. Much of this preliminary work, however, is tending rapidly into fundamental questions, and the time has been reached at many of the forest experiment stations for a material expansion of the fundamental investigations which have already been initiated and for the beginning of many others.

The Bureau of Plant Industry

The investigations in forest pathology of the Bureau of Plant Industry are conducted independently in part and in part in cooperation with the Forest Service at the forest experiment stations and at National Forest District Headquarters. One pathologist each has been detailed to the Northeastern and Appalachian Stations. Two pathologists at Portland, Oregon, cooperate with the District Headquarters and the Pacific Northwest Station. A staff of 4 pathologists is already working in California, and one pathologist has for some years covered the forests of Arizona and New Mexico cooperating with the District Headquarters and the staff of the Southwestern Station. An additional staff of 7 men covers all parts of the United States from Washington as a headquarters. Present appropriations for research in forest pathology, including shade-tree investigations, total about $108,000.

The Bureau of Plant Industry has made a very large contribution on the taxonomy and life histories of forest tree fungi and on the description of the damage done to trees. It has worked on the pathological relationships to the forest for a limited number of diseases. On damage surveys years of work by a small force have made only a small beginning, but it is practically the only work of its kind that has been done. In prevention and control, silvicultural measures of different kinds have been worked out for a limited number of diseases in a few western types and for two of the most destructive eastern diseases. Measures for the prevention and control of damping off have been perfected for the coniferous species commonly used in artificial forestation.

Work now under way is centered very largely on damage surveys,

prevention and control through silvicultural measures, and on pathological relationships. A relatively small amount of work deals with taxonomy and life history.

Bureau of Entomology

The Bureau of Entomology cooperates with the University of Minnesota in maintaining a forest entomologist at the Lake States Forest Experiment Station. Entomologists are stationed at the Northeastern and Appalachian Stations. A group of four forest entomologists with headquarters at Palo Alto cooperates with the western Forest Experiment Stations and National Forest Districts, in accordance with varying annual requirements. Field stations are also maintained in the West at Coeur d'Alene, Idaho; Ashland, Oregon; Kanab, Utah, and Halsey, Nebraska, with one entomologist at each except Coeur d'Alene, which has two. A field station is also maintained at East Falls Church, Virginia. Two entomologists work out from Washington, D. C. Appropriations now available for the above investigations in forest entomology and for control measures total $75,000. In addition about $80,000 is expended annually on research to prevent the spread of and to control the gypsy and the brown-tail moths.

The Bureau of Entomology has done a large amount of work on the taxonomy of forest insects, chiefly of the genus *Dendroctonus*. It has done much work on the life histories of the more important insects. Surveys of damage have for the most part been extensive. A good deal of research has been done on control measures chiefly of various western species of Dendroctonus, but also on the introduced gypsy and brown-tail moths in New England. Research leading to the introduction of parasites and natural enemies of these moths has been particularly effective.

The research in forest entomology is beginning to lean heavily to the fundamental ecological causes of insect periodicity. The possibility of measures of control through special silvicultural adaptations rather than costly control measures, such as barking of trees, is also being emphasized.

Other Bureaus

The Weather Bureau cooperates with the Forest Service in the maintenance of the Wagon Wheel Gap branch of the Rocky Mountain Experiment Station. It is also in several forest regions making investigations of the relation of climate and weather to fire, independently and in cooperation with several other organizations. The fire weather investigations were placed on a much more substantial basis on July 1, 1926.

The Bureau of Soils has occasionally assigned investigators to different stations upon request for research upon special problems such as detailed soil studies of permanent investigative areas.

The Biological Survey has also detailed men for special protection studies such as the poisoning of rodents in connection with artificial forestation and the control of porcupine damage.

ADVANTAGES AND HANDICAPS OF REGIONAL FOREST EXPERIMENT STATIONS

The chief advantages for research at the regional forest experiment stations include the following:

They bring to the Department of Agriculture a national conception

of the forest management and protection problems and the possibility of concerted national attacks when this kind of treatment is required. An example of an essentially nation-wide project now being attacked by the regional forest experiment stations is that of growth and yields. Another is a series of reports on forest management for all the important forest regions of the country.

The stations insure a regional point of view and attack on regional problems without restriction by boundaries of political subdivisions. Nearly all of our forest regions and most forest types cover more than one State and many of the forest problems are regional.

The regional forest experiment stations have research in forest management and protection as their sole objective. They have the advantage of full time research for members of their staffs. There are no possibilities that the stations themselves can become submerged in much larger organizations with many other objectives. When manned with a well-rounded-out staff of investigators, many-sided attacks on both regional and national problems are possible and the stations have the opportunity to become forestry centers of commanding influence. They have all the inspirational and other advantages which attack on a single problem of national importance will bring. The stimulus to the research staff may be extended to other research agencies in the region, and may be made a strong influence in the general development of both public and private forestry. The regional forest experiment stations are also proving themselves directly or indirectly to be valuable correlating agencies for all forest research in their respective regions.

When adequately manned these stations have been able to cover necessary preliminary investigations very rapidly and are now in several cases ready for or beginning urgent and important fundamental work.

Since it is possible to avoid duplication by attacking regional problems as a unit without regard to the boundaries of political subdivisions, the regional forest experiment stations constitute one of the cheapest and most effective forms possible for Federal contributions to this class of forest research.

The great handicap of the regional forest experiment stations is the rapidly growing demand for answers to specific problems growing out of the development of both public and private forestry. Encouraging though this pressure may be as an indication of progress in the utilization of our forest land, it sometimes necessitates more emphasis on immediate questions than the most efficient conduct of the work alone would require. Other handicaps of inadequate funds and of difficulty in obtaining suitably trained men are common to all organizations doing forest research.

RANGE EXPERIMENT STATIONS

The investigations of the Forest Service in forest range management and the establishment of range experiment stations to handle them have grown out of the administration of livestock grazing on the National Forests. The Forest Service has been made responsible in the Department of Agriculture for research on the nonforested ranges of the public domain as well as those of the National Forests because of the similarity in many respects of the problems. The work, however, is necessarily being conducted in cooperation with several other bureaus of the Department of

Agriculture and with some of the Western agricultural colleges. The tentative plans towards which the Forest Service is working in the creation of range experiment stations and the progress made are outlined below. The plans are broader than the forest ranges alone and provide for the nonforested public domain.

Northern Rocky Mountains and Adjacent Plains Region: including Montana, western North and South Dakota, northern Idaho, and the bulk of Wyoming; present investigative staff one man who is able to cover only Montana; allotment about $3,000.

Southwestern Region: including southern Colorado, New Mexico, Arizona, western Texas, and the portion of southeastern California adjacent to Arizona; two branch stations established, the Santa Rita in southern Arizona and the Jornada in New Mexico; work of the investigative staff of five men is now confined largely to these branches and to the National Forests; allotment about $17,000.

Great Basin Region: including Utah, Nevada, southern Idaho, southwestern Wyoming, and northern Colorado; work of investigative staff of two men now largely concentrated at the Great Basin Station on the Manti National Forest, and in cooperation with the United States Sheep Experiment Station of the Bureau of Animal Industry; allotment about $12,000.

California: including the bulk of the State; no work now being done.

Washington and Oregon: investigative staff now one man; allotment about $4,000.

Eastern United States: a little work being done by the Southern Forest Experiment Station.

The total staff for range investigations is now 10 men, with funds aggregating about $50,000. The tentative territorial division of the West among the range experiment stations and that for the forest experiment stations should be correlated and might result in advantageous modifications of either or both plans.

The range experiment stations have done preliminary work on the life histories of at least 6,000 of the numerous western forage species and much more intensive work on possibly 3,000. Ecological relationships of forage types have been intensively studied at a few places only, the work in central Utah being the outstanding example. The influence of forage on erosion, etc., has been intensively studied under one set of conditions in central Utah. Numerous tests of introduced plants for artificial reseeding of the ranges have been made. The control of poisonous plants has been studied. On food values the amount of general observation is already rather large. The relation of livestock grazing to forest reproduction has been intensively studied in a few western regions where it seemed to be critical. A relatively large amount of work has been devoted to the development of systems of forest range management for different classes of livestock. Work has also been done on the relation of fires to forage and considerable preliminary investigation of the carrying capacity of different ranges for different classes of livestock.

The work of the Forest Service has been supplemented by chemical analyses made in the Bureau of Chemistry and at State Agricultural Experiment Stations of possibly 25 per cent of the more important western forage plants. Additional work by the Bureau of Chemistry in cooperation with the Bureau of Animal Industry has determined the poisonous

principles for the more important western poisonous species. The Bureau of Plant Industry has attempted to introduce some foreign forage plants and has made material progress on the taxonomy of western forage plants in cooperation with the range stations. The Biological Survey has investigated methods of control of forage-eating rodents and predatory range animals. The Bureau of Animal Industry has studied the breeding, feeding, and management of range sheep. Although a few of the investigations, on ecology and influences, have been fundamental most of the work has been of the application type. The great bulk of the work on most problems is still in the future.

The advantages and handicaps for research at the Federal range experiment stations are substantially those outlined for the forest experiment stations.

FOREST PRODUCTS LABORATORY

The Forest Products Laboratory, in which improved timber utilization is the main objective, is a forest research center which parallels in another field that already indicated for the forest experiment stations. The Laboratory has been developed at Madison, Wis., by the Forest Service and the Bureau of Plant Industry of the Department of Agriculture, in cooperation with the University of Wisconsin. It is designed to cover the utilization of wood and closely related forest products for the entire United States. The Bureau of Plant Industry conducts investigations in the pathology of forest products with a staff of five pathologists; and the Forest Service, with a staff of about 75 engineers, chemists, physicists, wood technologists, and foresters, and a considerably larger nontechnical and clerical force, covers much of the remainder of the forest products field. The University contributes quarters, heat, power, etc. The Bureau of Entomology is considering the advisability of placing a forest products staff at Madison. Plans of the Forest Service now call for the establishment of a Biological Section which, among other things, will serve as a central laboratory for the Forest Experiment Stations. Such a section will constitute an excellent means for the closer correlation of silvicultural and forest products research. Present Forest Service allotments of about $400,000 are supplemented by about $75,000 additional of funds contributed by other Federal Departments or by the forest industries. The Bureau of Plant Industry allots about $16,000. Additional groups of products investigators of about 12 men have headquarters at Washington, D. C., Portland, Oreg., San Francisco, Calif., and Missoula, Mont., and necessitate an allotment of about $60,000.

The forest products research of the Department is very largely concentrated at Madison, however, and it is planned to continue this arrangement indefinitely.

The Forest Products Laboratory resulted from the combination of several small laboratories in different parts of the country, each of which was responsible for the investigation of different phases of timber utilization. The scattered laboratory plan proved ineffective. It was necessary to duplicate equipment. It was difficult to prevent overlapping of effort and to obtain effective correlation. The stimulus from contact of different groups of men working on closely related problems was lacking. Unlike regional forest and range experiment stations, where most of the work has to be

undertaken in the woods and is distinctly local or regional in character, much of the utilization research can be brought to a central laboratory and is national in character. Practically the entire staff was therefore concentrated at Madison in 1910. The stimulus to the staff and the benefits to the work itself afforded by the coordinated many-sided attack on closely related phases of what is in the last analysis a single national problem has justified the change in plan in the most remarkable way. The stimulus from coordinated attack within the organization proper is supplemented and broadened by contact with a large group of University scientists. The Department of Agriculture and the University of Wisconsin and the general public have hardly begun to realize the possibilities of service from this institution.

Without restriction in its activities by State boundaries, the Forest Products Laboratory is in a particularly fortunate position to grasp national utilization problems, and to undertake work on such national projects as the comparative strength or chemical properties or the comparative pulping values of all American species. The same advantage holds for regional questions.

A further advantage is that for full-time research by the members of its staff. One of the chief handicaps of the Forest Products Laboratory which tends to delay progress in fundamental research is that also indicated for the forest experiment stations—the growing public pressure for immediate answer to special utilization problems. These are legitimate problems, the solution of which would immediately stimulate better utilization of timber, and it is not always right or possible to deny them even though the national program of better utilization might be more rapidly advanced in the long run by a greater concentration on fundamental research.

The Forest Products Laboratory has made a substantial contribution to our knowledge of the structure of wood, but largely on the grosser structure. It has tested for strength all of the commercially important and many relatively unimportant American species, for timber cut from virgin stands, and has begun on second-growth timber. A great deal of work has been done on built-up articles, mainly containers and airplane parts. It has done many years' work on physical properties of wood, such as heat and moisture transmission and the relation of these to working and to seasoning. It has devoted years of effort to the study of the chemistry of wood, but for the most part with particular reference to such processes as pulp and paper making and hardwood distillation, wood hydrolysis, etc., although a beginning has been made in the study of the more fundamental chemistry of wood as a material. All of the preceding investigations have dealt indirectly with waste, but quite a number of projects, such as the cutting of small dimension stock direct from the log, have been aimed primarily at waste reduction.

The work of the Forest Service on the mechanical problems of wood impregnation with wood preservatives of all kinds, and on actual service tests of various materials such as ties treated with different preservatives, has been supplemented by equally comprehensive work in the Bureau of Plant Industry on wood-destroying fungi, their environmental requirements, and the toxicity of preservatives.

The work of the Forest Products Laboratory has covered much of the preliminary field in forest products. The largest gap for this kind of research includes various phases of waste in the woods and in manufacture and remanufacture. Programs of the Forest Products Laboratory are gradually, therefore, tending more and more toward fundamental research. Strength properties are being determined for second-growth timber. Heat and moisture relationships and minute structure and its relation to strength and physical properties are receiving increasing emphasis. More and more work is being devoted to the fundamental chemistry of wood. The properties of wood are being studied with reference to the conditions under which it grew. Environmental requirements of wood-rotting fungi and the fundamental chemistry of preservatives are becoming more and more conspicuous in the program.

FOREST ECONOMICS

Investigations in forest economics have been the least developed in staff and appropriations of those now conducted by the Forest Service. The present staff of six men has been supplemented from other research units from time to time as needed for special and urgent investigations. Current allotments which have been in the neighborhood of $25,000 a year, have very recently been increased by $35,000 for a comprehensive long-term study of forest taxation.

A Federal organization for investigations in forest economics has unquestionable advantages in leadership and in unrestricted national movement for the study of such regional and national questions as forest taxation and a comprehensive forest survey.

Many of the investigations of the Bureau of Agricultural Economics on land questions have considerable direct as well as indirect value in forest economics.

The economic research organization of the Forest Service has to its credit two rather comprehensive compilations of the previously scattered data on timber stands, acreage of forest lands, total cut and drain on the forest, replacement of drain by growth, and the most comprehensive compilation on the forests of all other countries which has ever been made. It has investigated some phases of the business economics of the lumber industry, and the pulpwood and pulp situation in the United States including the possibility now and in the future of meeting paper, pulp, and pulpwood requirements from home-grown materials. It has undertaken a series of studies of the wood-using industries of various States. Before the work was taken over by the Bureau of the Census the Forest Service made a number of censuses of lumber cut, pulpwood consumption, pulp production, etc. Important though less comprehensive investigations have included the effects of forest devastation in one State, lumber distribution and the relation between transportation and prices, stumpage and lumber prices, the status of the substitution of other materials for wood, and a beginning on forest taxation.

The work of the present and of the immediate future includes a comprehensive study of forest taxation, the current compilation of data on timber resources, collected by various other agencies, the continued study

of the transportation and distribution problem in its relation to timber growing, and the collection of data bearing on the financial feasibility of timber growing.

2. OTHER FEDERAL DEPARTMENTS AND ORGANIZATIONS

DEPARTMENT OF COMMERCE

Bureau of the Census

The Bureau of the Census of the Department of Commerce has for many years collected invaluable statistical data in periodic censuses on the cut of such forest products as lumber, pulpwood, fuelwood, and railroad ties, the more important of which are now being made annually or biennially. Although the Forest Service contributed in the past in order to obtain more frequent collection of data and still cooperates, the Bureau of the Census with its national organization is the best equipped agency for effective work on censuses of this sort.

In addition, the Bureau of the Census has assisted the Forest Service in obtaining data on lumber distribution for several years. In connection with its general agricultural censuses the Census Bureau has obtained also in the past and will in the future be able to obtain valuable data on farm woodlot acreage, cut, returns, etc.

The Bureau of the Census during the past three or four years has also been collecting from associations and publishing mill prices of lumber in the general "Survey of Current Business" of the Department of Commerce. A few wholesale prices also are published, but no retail prices.

The cost of the 1919 decennial census of lumber and allied products, including some special forest products inquiries, was approximately $220,000. This includes the cost of collecting the data and compiling the statistics. The cost of collecting the data and compiling statistics in the less complete biennial census of 1923 for the same group of industries was approximately $65,000.

Bureau of Foreign and Domestic Commerce

The Bureau of Foreign and Domestic Commerce has for many years collected statistics on the imports and exports of forest products along with those of other materials, and is the only organization equipped for this work.

Two of its divisions deal with lumber and pulp and paper, respectively, among other forest products. In these divisions questions of domestic marketing and export possibilities are studied, as are also ways and means of bringing about improved industrial practices in utilization and otherwise. The general point of approach in the latter investigations is that of commerce, in contrast to that of the resource and its perpetuation through best use and new growth which obtains in the Department of Agriculture. This necessarily brings the two Departments into the same field and cooperation is necessary in order to avoid duplication of effort. The field is so large, however, and so much remains to be done that there is ample opportunity for the work of both Departments without duplication.

Bureau of Standards

The Bureau of Standards has conducted a series of investigations on problems of paper manufacture which it is well equipped to continue. It

has also been making a series of investigations on fireproof construction with wood as one important material. An investigation of paints and varnishes for all materials is, in the case of wood, being undertaken in cooperation with the Forest Service.

The Simplified Practice Division of the Bureau of Standards has under way a series of investigations on a simplified practice and waste utilization which includes a wide range of industries and materials. Where wood or the forest industries are concerned, the field overlaps that of the Forest Service and cooperation is necessary to prevent duplication.

The Housing Division of the Bureau of Standards also has in process a comprehensive series of investigations on house building which goes into various problems of the materials used, of which wood is one. Building codes and the utilization of short and odd lumber lengths are among the important subjects which are being covered.

TARIFF COMMISSION

The Tariff Commission now conducts investigations of manufacturing costs and returns and other competitive conditions as a basis for executive and legislative action on tariffs. These investigations deal with forest products whenever the situation demands. They have already covered such products as logs, lumber, shingles, wool production, and that of beef cattle.

FEDERAL TRADE COMMISSION

The Federal Trade Commission is concerned with unfair methods of competition in commerce in connection with which economic investigations of domestic industry and interstate and foreign commerce are frequently necessary. These economic inquiries, which in some cases deal with forest industries, are sometimes inaugurated by the Commission upon complaint or upon its own initiative, but are more frequently undertaken by direction of Congress.

INTERSTATE COMMERCE COMMISSION

The Interstate Commerce Commission regulates commerce on common carriers, and often has occasion to investigate transportation charges on forest products. Its dockets are full of lumber cases, for example, which in general have grown out of the shifting of the lumber cut from region to region without sufficient lapse of time, as in the case of most other commodities, for the rate structure to stabilize.

TREASURY DEPARTMENT

The Timber Section of the Internal Revenue Bureau, in connection with its administration of the Federal income tax, collects a very large amount of the most valuable economic information on private timberlands, including areas of timbered and cut-over lands, timber stands, timber values, and changes of ownership. The Section has access to all the financial data reported in the income tax returns of the forest industries, but no machinery for the systematic compilation of such data.

3. STATE DEPARTMENTS

The executive departments of many States include forestry among their activities, and in some cases such specialties as forest pathology and

entomology. Since forest research also has been and should continue to be a phase of these activities in some instances at least, the State departments in general must be recognized as having an important place in the national structure of research organizations.

STATE FORESTRY DEPARTMENTS

Thirty-four States now have State forestry departments—the first, New York, established in 1885—with a gradual increase in number still under way. Three other States have State Foresters.

The chief efforts of the State forestry departments have been in fire protection on State and private lands, general educational efforts, advice to private land owners, the growing and distribution of forest tree nursery stock, and in fewer instances of which New York and Pennsylvania are outstanding, the acquisition and administration of State forests. These purely administrative activities combined frequently with a more or less strenuous financial and political struggle for existence have ordinarily militated against much research.

Pennsylvania only has a distinct research organization and as a result leads the States in the scale of its work. The program of the Department proper deals primarily with problems of artificial forestation, growth and yields, forest management, forest fires, and the life histories of forest trees. The Department includes the State Forest Academy at Mont Alto, which conducts investigations on a substantial program of its own, centering on much the same kind of problems but including also forest diseases and the utilization of forest products.

Not far behind Pennsylvania are Maryland[1] and New Jersey, both of which have outlined comprehensive programs of about thirty projects dealing with forestation, forest management, utilization, protection, and economics. Falling roughly in a third group from the standpoint of volume of work are such States as New York, New Hampshire, California, and Massachusetts, which have from three to ten projects in their investigative programs. The program in New Hampshire is concentrated on planting, a timber survey including both resources and production, and on slash disposal. New York has under way a rather extensive study of plantations which it plans to continue indefinitely and is studying also growth and yields and forest diseases. A considerable group of States, in fact the remainder of those with forest departments, have either a very small number or no research projects under way.

In the programs of the State forestry departments artificial forestation has been one of the most conspicuous lines of work. Many States grow and distribute nursery stock, and the need for good stock at reasonable cost and the equally great need for sound advice to private owners on the trees to plant and methods of planting have necessitated investigations. Most of the States, therefore, which have attempted any research have worked on one or more phases of artificial forestation.

Forest surveys have also figured conspicuously in the research ac-

[1] The Maryland State Department of Forestry functions under the supervision of the Regents of the University of Maryland, and for this reason might have been discussed equally well under Section 4, which follows.

tivities of the State forestry departments. In most cases they have covered the requirements in quantity, quality, etc., of the State wood-using industries. Maryland and Wisconsin have conducted independent surveys of this character, while nineteen States have cooperated with the Forest Service in making similar surveys. In some twenty-nine of the States independent or cooperative surveys have attempted to get at the resources in timber or forest land, or both. The most intensive land classification project so far attempted in the United States is under way in Michigan.

Several State departments, including Pennsylvania and Indiana, have to their credit more or less comprehensive dendrological studies. For the rest the research programs cover a somewhat scattered group of projects, including silvicultural methods, volume tables, growth and yields, various phases of fire protection, and tree diseases. In quite a number of cases States which have been unable with the resources available to undertake research projects alone have cooperated with the Federal Government.

No general principles which will apply universally can be laid down for the investigative work to be done by State forestry departments. The State policy as to the conduct of research by the State forestry department or the State agricultural college or agricultural experiment station may have a controlling influence. Exigencies of appropriations or personnel may be equally important. Undoubtedly, however, there is the opportunity in a good many States for effective research by the forestry departments on a far larger scale than they have ever attempted. For example, it can well include as a minimum investigations of artificial forestation, resource or industrial surveys, and protection against fire, in all of which the State departments are deeply concerned.

Practically all States have local problems of timber growing or use or of forest economics which should be handled by State agencies. These local problems may involve merely detailed application of general results made available by other research or they may require intensive research on their own account.

In States where the great bulk of the forest land is in farm woodlots, the connection with general farm research may be so close that most or all investigative work can best be centered at the agricultural college and experiment station. In other cases a large proportion of the forest land may be in large commercial holdings which are located in forest districts with relatively small amounts of agricultural land, so that the State forestry organization has a much closer contact and a correspondingly better knowledge of the forest problems of the State and may be somewhat better equipped to handle some phases at least of the research program of the State. The State university or agricultural college or experiment station has obvious advantages in a research atmosphere. The State forestry department may be handicapped in giving thoroughly efficient supervision to research, particularly if the amount is small; but even a small amount of research in a State forestry department gives a knowledge of methods and a point of view on the entire forestry problems which is invaluable in a well-rounded-out forestry development. Many State forestry departments which can at best attempt only a small amount of research may find that the most effective means for their contribution

will be in the form of cooperation with other agencies, State or Federal, which have large research organizations.

STATE ENTOMOLOGISTS AND PATHOLOGISTS

A number of States have entomologists or pathologists or both in their executive departments. While records showing how much research is being attempted are unavailable, it is known that New York has one man who devotes his full time to forest pathology, and Pennsylvania has one who devotes part time to the white pine blister rust.

4. UNIVERSITIES AND AGRICULTURAL EXPERIMENT STATIONS

STATE INSTITUTIONS

The relationship of State universities, agricultural colleges, and agricultural experiment stations varies in different States from centralized to entirely separate location and control. A number of State universities contain forest schools; in other States forest schools are a part of the agricultural colleges. The State foresters of some States are attached to the agricultural colleges and of others to the agricultural experiment stations, instead of being assigned to a State department.

This diversity in organization among the States, together with a great difference in the facilities for forest research, has resulted in corresponding differences in the responsibility for it. There are marked differences in the amount and character of research attempted, and as might be expected, the State institutions which include forest schools or State foresters are ordinarily attempting more than those which do not.

New York

New York maintains a State College of Forestry as a part of Syracuse University. The faculty of some thirty or more members, the largest in any American forest school, conducts investigations on a comprehensive program which includes groups of projects on artificial forestation, ecology, volume, growth and yields, thinnings, natural reproduction, brush disposal, kiln drying, air seasoning, the chemistry of wood and of pulp and paper, lumber manufacture and markets, and forest entomology and pathology. Several studies of the requirements of the wood-using industries within the State have been made independently or in cooperation with the Forest Service. Considerable assistance in research is rendered to faculty members by graduate students working for a master's degree. The number of these students is gradually increasing, and now amounts to about ten. An attempt is being made to obtain a special appropriation for research. The school has a forest products laboratory and several field experimental and demonstration areas in the Adirondacks and in other parts of the State.

Closely connected with the college but independent in organization is the Roosevelt Wild Life Experiment Station, which was established in 1919. This station has a staff of some eight men, most of whom devote practically their entire time to research. The station does not confine

its activities to the Adirondacks but reports 6 of the 21 projects now under way as located in the West, chiefly in the Yellowstone and Rocky Mountain National Parks. Series of publications have been issued by both the station and the State College of Forestry.

New York State also maintains a school of forestry as a part of the State College of Agriculture at Cornell University. The faculty includes a research professor who devotes his entire time to research. It is hoped eventually to have two. His efforts are supplemented by part-time research by other faculty members and by the employment of teaching assistants working for advanced degrees who do some research. Work is under way in the Forest School or by members of the university staff in other departments and colleges on groups of projects dealing with dendrology, anatomy, physiology, soils, artificial forestation, volume, growth and yields, silvicultural management, fungus and insect diseases of forest trees, and the preservation of wood. The school is anxious to obtain an experimental and demonstration forest of about 1,000 acres near Ithaca.

Minnesota

In Minnesota the State University, agricultural college, and experiment station are centralized. The agricultural college includes a forest school and a forest experiment station has since 1909 been maintained as a part of the agricultural experiment station in connection with the forest school. The University has since July 1, 1923, cooperated with the Federal Forest Service in the maintenance of the headquarters of the Lake States Forest Experiment Station. As a part of the cooperative arrangement, the Directorship of the Cloquet State Forest Experiment Station and of the Federal Lake States Station is centralized in a single man so that close cooperation is insured between the State and the Federal government. The State is now devoting to research practically the full time of two technical men, supplemented by additional work by the Forest School faculty, and expending about $11,000. The investigations deal with such questions as the management of the Cloquet experimental demonstration forest, methods of cutting, nursery practice, and artificial planting, volume, growth and yields, pathology, the effect of water level in swamps upon tree growth, thinnings, and the possibilities in the management of cut-over lands.

California

In California the university, agricultural college, and agricultural experiment station are centralized, with a forest school in the agricultural college. The school was organized under a plan allowing one-half of each college year for research by each member of the faculty. Although it has not so far been possible to follow the plan literally, an unusual opportunity for research has been afforded. Several small experimental forests are already available, and plans contemplate additional tracts. The work under way consists primarily of groups of forestation, silvicultural, growth and yields, utilization, and range problems. Considerable work has been done on redwood yields. An investigation of the structure of the cellulose molecule by X-ray methods is under way at the Southern Branch of the University. The University has to its credit a comprehensive publication on the silva of California, as well as a series of reports on other phases

of forest research. The University cooperates with the Federal Forest Service in maintaining the headquarters of the California Forest Experiment Station.

Michigan

Michigan maintains a forest school as a part of the Michigan Agricultural College, with which the State agricultural experiment station is closely identified. Several of the agricultural experiment station tracts are available largely or altogether for forest research. The State forest nursery for the distribution of stock to private owners is administered by the college and experiment station. Research on various phases of silviculture, forestation, growth and yields, forest taxation, and forest insurance is a faculty activity in connection with the agricultural experiment station.

The Forest School of the State University controls a number of experimental and demonstration tracts on which research in artificial forestation and silviculture has been under way during the past twenty years. Only faculty research with student assistance is attempted.

Connecticut

The Connecticut Agricultural Experiment Station has three foresters on its staff, one of whom is located at the Agricultural College and devotes the bulk of his time to teaching. The other two are engaged mainly on research, and an attempt is being made to add to this staff. The combined program of the Experiment Station and College of Agriculture includes a land utilization and soil survey of the State, investigations of artificial forestation, the relationship of forest types and soils, forest tree diseases, thinnings, volume, growth and yields, chestnut replacement, and the silvicultural improvement of deteriorated stands.

Other States

The University of Washington has a forest school in the State University and a forest products laboratory, and is acquiring an experimental and demonstration forest. Faculty research is confined chiefly to economics, utilization, and artificial forestation. The University is cooperating with the Forest Service in a study of the forest resources and the wood-using industries of the State. A course in forestry is given at the State Agricultural College, a separate institution, but so far little research has been attempted.

The Iowa Forest School is a part of the State Agricultural College. Together they have a fairly comprehensive research program covering woodlot management and forest products with chief emphasis on artificial forestation.

The Vermont Agricultural Experiment Station, which is a part of the Agricultural College, has been doing valuable work on light requirements and tolerance of forest trees.

The University of Kentucky in connection with the Agricultural College and Experiment Station has recently acquired and plans to devote to forest research and demonstration an area of approximately 14,000 acres. For the Robinson Sub-experimental Station, of which this tract is a part, an annual appropriation of $25,000 covers forest research and all types

of agriculture. At present one forester is employed who is making a comprehensive survey of the timber tract. It is hoped when the survey is completed to initiate studies in forest management, reforestation, and related questions to determine methods and the financial feasibility of forestry under similar conditions. It is expected that additional acreage will be obtained.

The State Forester of Ohio is attached to the Agricultural Experiment Station. He has an assistant who devotes most of his time to farm woodlot problems. The research program includes primarily projects relating to silviculture, planting, yields, and forest surveys. The Experiment Station has cooperated with the Forest Service in a study of the wood-using industries of the State.

The New Hampshire Agricultural College employs two foresters for instructional work, who have been able to do some research on growth and yields, thinnings, and natural regeneration, mainly of white pine. Plans are being made for the employment of a forest investigator to be attached to the agricultural experiment station.

Pennsylvania has a forest school in connection with the Agricultural College and Experiment Station. One full-time investigator is being added to the staff of the Agricultural Experiment Station. The program includes investigations in artificial forestation, the financial feasibility of forest management, the role of soil bacteria in the immunity of black locust from borer attacks, the determination of conditions necessary for the natural reforestation of waste lands, growth and yields, durability of shingles, dry-kiln efficiency, and the value of small trees in logging.

One forester is attached to the Massachusetts Agricultural College and Experiment Station. The college has an experimental forest of several hundred acres and since July 1, 1923, has cooperated with the Forest Service in the maintenance of the headquarters of the Northeastern Forest Experiment Station.

The State Forester of Texas is a member of the Agricultural College. State forests are being acquired for experimental and demonstration purposes.

In Idaho the university, agricultural college, and experiment station are centralized, with the forest school in the agricultural college. The forest school faculty is employed for the full year in order that the summers may be devoted to research. The program has so far included studies of volume, growth and yields, silviculture, land classification, the preservation of forest products from decay, and other products problems.

The Oregon Forest School is a part of the agricultural college, as is also the agricultural experiment station. The school has a small experimental forest and plans to use the much larger State forest which is now being acquired.

The Forest School of the Georgia Agricultural College has a 300 to 400 acre woodlot at its disposal.

In Colorado the State Forester is a member of the agricultural college and experiment station.

The Illinois legislature has passed a measure creating a forest experiment station as a part of the State Agricultural Experiment Station but has not yet made an appropriation.

The University of Louisiana has by the employment of a forester taken the initial step toward the establishment of a forest school in the agricultural college.

Practically all of these institutions are undertaking research, but in somewhat smaller amounts than the first institutions mentioned.

Nearly twenty other agricultural colleges and agricultural experiment stations attempt a limited amount of forest research, ordinarily not to exceed two or three projects.

CHARACTER OF FOREST RESEARCH AT STATE INSTITUTIONS

The programs of the State universities, agricultural colleges, and experiment stations are characterized primarily by work on various phases of artificial forestation, silviculture, and forest mensuration. Independently or in cooperation ten States have made studies of wood-using industries and forest resources. The relatively little work on forest products is confined mostly to the durability of wood and the preservation of such farm products as fence posts. Work on forest tree fungi and insects appears in a few programs. Investigations other than those which are now under way are widely scattered and relatively few projects deal with the more fundamental problems.

During the past thirty years, however, a surprisingly large number of scattered investigative projects, undertaken by various State universities, agricultural colleges, and experiment stations have dealt with different fundamental phases of forest research such as light, soils, root development, and forest influences. Many of these investigations have made valuable contributions to our knowledge of the science underlying forestry. Some of those with the highest intrinsic value, however, have fallen short of the greatest usefulness because of their remote relationship to forest management as a practical problem.

ENDOWED UNIVERSITIES

Yale

One of the most comprehensive research programs at endowed universities is carried on by the Yale School of Forestry, and this is supplemented by some work in other departments of the university on forest research or closely related subjects. The combined program includes investigations of dendrology, genetics, nursery practice and planting, soils, various phases of silviculture and management, thinnings and improvement cuttings, brush disposal, volume, growth and yields, wood technology, and a group of projects on lumbering. One member of the Forest School faculty is able to devote a large part of his time to investigations in forest ecology and silviculture. Another will be able to devote practically his entire time to investigations of tropical woods. The income from an endowment for forest research is used chiefly for the employment of graduate students. The school plans to relieve the older members of the faculty for further research by the employment of instructors and additional graduate assistants as rapidly as additional endowments become available. The school owns several experimental and demonstration forests in New Hampshire, Vermont, and Connecticut, now totaling about

3,000 acres, and utilizes additional areas of several thousand acres. A number of publications covering research results have already been issued.

Harvard

The Harvard forest of 2,000 acres at Petersham, Massachusetts, is used for both research and demonstration. It is planned to develop intensive research of a fundamental character, and the income from a recent endowment will be used largely for this purpose, as will also a part of the income from the forest. The staff now consists of a director, an assistant director, and an instructor, in addition to whom there are usually from four to eight graduate students. A part of the investigative program centers around the management of the experimental demonstration forest and includes methods of cutting in several types, the improvement of inferior or deteriorated stands, thinnings, growth and yields, and artificial forestation. The program also includes some work on forest entomology and a study of light and soils. An investigation is being made of the factors influencing the marketing of local timber. At the Bussey Institution one investigator is devoting practically full time to various problems of wood structure or anatomy, such as structure in relation to identification, properties and uses, physiology, and pathology. The Arnold Arboretum has for many years conducted various dendrological studies, including the introduction of exotics. For the latter foreign exploration is frequently necessary. The outstanding publication on the silva of the United States has already been mentioned. Other investigative results have also been issued in a series of bulletins and scientific papers.

Other Universities

Many other endowed universities have under way more or less research which deals directly or indirectly with forests, of which, however, only the most fragmentary kind of record is available. In many cases, as at Johns Hopkins and Leland Stanford, this work deals with various phases of botany or plant physiology or ecology which have a direct or indirect bearing upon forest trees. Dendrology has a place in a number of institutions, such as Tulane. Some work is being done on forest pathology, as, for example, at Brown and at Washington University in St. Louis. Undoubtedly also out of the many universities with instruction in entomology a few are investigating forest insects. Some work is being done on forest geography and forest economics, as at Chicago, Kansas, and Pennsylvania.

ADVANTAGES AND HANDICAPS FOR RESEARCH AT UNIVERSITIES AND AGRICULTURAL EXPERIMENT STATIONS

At Institutions Having Forest Schools

Where forest schools are a part of State or endowed universities or agricultural colleges there are good opportunities for three more or less distinct classes of research. The first is the part-time research by faculty members, whose chief duty is the instruction of students. Nothing else gives quite the same background in the training and development of teachers. In many institutions, however, the teaching burden is so heavy that relatively little time is available for research, and unless ample time is allowed, progress is necessarily slow. The California plan of allowing faculty members one-half of each academic year for research alone is very advantageous from this standpoint.

A second class of research is that undertaken by research professors who are not required to take part in instruction. In addition to the rapid progress which can be made in the solution of forestry problems, the influence of such research upon students and upon the remaining members of the faculty is most beneficial. In a number of institutions such as Yale and Harvard the instructional duties of many of the senior faculty members are relatively light and a large amount of time is available for research.

The third class is that of graduate students with or without fellowships. Funds are available in a few institutions for fellowships of this sort, and endowments permit the employment of students in others. Many problems require only the one or two years' work which are ordinarily devoted by graduate students to the preparation of theses. If not attacked in this way they are usually neglected by other research institutions. In addition to the progress which can be made in the solution of forestry problems, graduate research has the highest value in the training of men for both research and teaching.

In general at universities or colleges with forest schools there are or can be developed very favorable opportunities for fundamental as well as for less intensive research. Men on such work are not subjected to the pressure which compels results for application within a specified time. There need, in fact, be no restrictions whatever concerning the kind of work which can be undertaken except lack of funds or the territorial restrictions which often obtain in schools supported by State appropriations. All such institutions have the great advantage of a research atmosphere, the stimulus which comes from scientific contacts, and in a good many there are or can be developed many-sided attacks on the forestry problem, including specialized subjects such as forest pathology, forest entomology, forest products, and forest economics.

A number of forest schools have already obtained experimental and demonstration forests as field laboratories for research in forest management or protection. Some have separate forestry or general botanical laboratories, and a few also have forest products laboratories.

European experience as well as our own has disclosed some of the handicaps of the forest school and university research. Projects have been selected in many instances because of individual interest of the investigator and not because they were the most important or urgent from either a national or a regional standpoint. Investigators who have been placed on their own responsibility have frequently resented direction or pressure for accomplishment as an infringement upon full freedom of action and as a result progress has been slow and too frequently research programs have existed more on paper than in fact. The burden of instruction, which has been the main duty, has made research incidental and served also to slow down the rate of progress. The relatively small size of a forest school as part of a university has tended to submerge forestry in the larger interests of the university. In universities without a forest school in which forest research has been attempted this submergence has been all the more marked. It is such conditions as these that are responsible in a number of European countries for the movement to establish forest research units directly responsible to the organizations which administer the State forests, and in the United States similar conditions have

been responsible for the relatively small research output of most of our forest school faculties.

At Universities without Forest Schools

At universities without forest schools there are also good opportunities for forest research. Botanical departments can investigate forest trees as well as other forms of vegetation. Work on forest pathology or forest entomology is frequently possible. Engineering and chemical colleges or departments have the opportunity for investigations of forest products. Departments of economics and geography have large fields of great importance which no one as yet has attempted to cover. There is the opportunity for both fundamental and applied work on subjects which are vitally important to the public welfare.

The chief handicaps are those already outlined for forest research at universities with forest schools, with the additional lack of a forestry background which the presence of a forest school would help to furnish.

At Agricultural Experiment Stations

The agricultural experiment station may or may not, from the standpoint of forestry, have the advantage of a forest school or State Forester attached to a closely connected agricultural college or State university. A forest school, or a single professor who gives courses in forestry, or a State Forester, should stimulate forest research by bringing up problems which require solution and aiding to give the work the necessary forestry background.

The timber crop in States which have farm woodlots should constitute an element in diversified farming. With or without a forest school the agricultural experiment station is better equipped than any other State agency to consider the interrelationship of all crops and to study farm production as a unit. Local problems, of which there are almost as many in forestry as in agriculture, are peculiarly the function of State institutions.

In States with large forest areas containing little or no agricultural land, the State experiment station may find it more difficult to acquire and maintain familiarity with forestry problems than the State executive department which has more direct responsibility. Such advantages may be partly or altogether offset by the lack of research atmosphere in the State forestry departments.

The agricultural experiment station also has a very distinct advantage which comes from investigations on soils, pathology, entomology, and climatic problems of other forms of plant life, all of which tend to furnish the many-sided attack on a problem the value of which is being increasingly recognized in all research.

A possible handicap in forest research at agricultural experiment stations not closely connected with strong forest schools or with the regional forest experiment stations, is the danger of submerging one or a very limited number of men on a specialized subject in an organization having in agriculture a largely different main objective.

5. INDUSTRIAL AGENCIES

A surprisingly large number of private timberland owners in the United States are either conducting or helping to support some research

in forest management. In some cases foresters are employed who conduct investigations for the land owner. In others, among which research on California redwood reproduction and management is a striking example, consulting foresters are called in. In still others the owners contribute cash or labor, or the use of land to universities or State or Federal organizations.

Lumbermen's and other associations are beginning to engage upon forest research. The Western Forestry and Conservation Association has recently organized a research department which is financed by subscription from a few concerns which are given special service, although general results are made public. At present two men are devoting full time and a third part time to this department. The California White and Sugar Pine Association has recently announced the employment of a forester under a similar plan.

National Research Council Bulletin No. 16, issued in 1921, lists more than 500 research laboratories in industrial establishments in the United States, including consulting research laboratories, of which nearly 100 are engaged upon or are equipped to undertake forest products research. The size and character of such research organizations differ widely. In the Brown Company, for example, with a research staff of a director, 28 graduate chemists, 1 mechanical engineer, 2 technical photographers, and 10 chemical assistants, the full time of 27 is reported as being devoted to research in pulp and paper making.

A part of the large research staff of the Du Pont Companies is devoted to research in the utilization of various wood products for such materials as grain alcohol, explosives, and cellulose lacquers. The Eastman Kodak Company has been assigning a part of the time of its large research staff to the modification of pulp and hardwood distillation products for films. Such products as bakelite and redmanol include wood in modified form and are the direct result of research by industrial laboratories. The fiber silks and other fabrics based partly or entirely upon wood have been developed by the industrial research chemist. Some concerns like A. D. Little and Company do consulting work on waste problems in lumber and pulp and paper manufacture. The Burgess Laboratories illustrate another type in which in part the effort is to work out improved forms of wood utilization such as balsam wool and either to dispose of the process or to manufacture the product directly. The number of concerns which employ one or more men for research on their manufacture or use of wood is gradually increasing.

The Pine Institute of America has recently been incorporated in the South with representation of producers of turpentine and rosin from the live tree or by distillation of the wood, owners of virgin or cut-over lands, and also dealers in turpentine and rosin. It is planned that the Institute shall among other activities conduct research in timber growing and protection and in utilization, the latter including chemical methods for utilizing wood, rosin, and turpentine. It is also the purpose to stimulate needed research by financial contributions or otherwise, and to aid its members as fully as possible in the application of results.

The pulp and paper industry has a large number of units which are doing research. Chief objectives in the past have been the standardization of processes in order to obtain the uniform products so important from

the commercial standpoint, and the development of a large number of special forms of paper. The research of pulp and paper companies is also responsible for minor improvements in the commonly-used processes of pulp making. The method used in the recovery of waste liquors in the soda process is an industrial contribution, as is also one promising process for the recovery of waste sulphite liquor. A very large amount of work has been done on various phases of the liquor recovery problem, not only by the pulp and paper industry but by other industries such as those which manufacture equipment. In a few cases individual companies are doing fundamental work on the pulping processes.

A relatively small number of the larger lumber and pulp and paper corporations maintain units for economic research, chiefly for the collection and interpretation of data which will assist in sales. Several of the forest industry associations collect and distribute data on production, orders, shipments, manufacturing costs, and prices, for the same purpose. Practically all private timberland owners have made estimates of their timber resources, almost exclusively, however, of merchantable material and not of the potential productivity of the land.

A small number of corporations have made inquiries into regional resources. The Southern Pine Association has made two surveys of the pine resources of the South which are fully as comprehensive as any heretofore attempted in the United States and which include also rough estimates of timber growth. The Woodland Section of the American Paper and Pulp Association has under way regional surveys of pulpwood resources. The Ohio Retail Lumber Dealers' Association maintains a chair of retail lumbering at Antioch College, Ohio, which in addition to instruction is to do research in accounting and the transportation and distribution of lumber in the State.

The efforts in forest research by industrial agencies fall roughly into two general classes. The first class includes the older forest industries in some of which, for example, wood is used in the form of lumber and without change except for cutting. These industries are doing themselves or financing relatively little research. Ordinarily that attempted has been fragmentary rather than comprehensive, and of brief rather than of a sustained character. It has usually dealt with restricted special problems without reference to the fundamentals on which an ultimate solution must rest. The general attitude towards research has been in part a reflection of materials long in use which it was assumed could hold their place in competition without the knowledge which research alone could furnish. It has been the result of a similar situation as to manufacturing processes, and a very large number of highly individualistic land holders and manufacturers.

The second class includes most or all of the newer chemical industries which manufacture highly modified and specialized forms of wood such as pulp and paper, fiber silk, lacquer, and bakelite. Some companies have developed by their own research the products which they now manufacture. Most of the individual companies in such industries maintain their own research units. Relatively few have undertaken fundamental investigations, but have confined their efforts to the investigations necessary to develop their products, to make their processes more efficient, or to standardize processes and products.

Many purely local problems in forest management or utilization, others which involve the working out of special applications, the development of special products which may or may not require fundamental research, the study of questions of business economics which directly affect the company or industry concerned, are among those which industrial agencies can well undertake for themselves.

The handicaps in forest research by industrial agencies include impatience for immediate results which may preclude the far cheaper and most effective fundamental research. Impatience may restrict research solely to those projects which promise results for immediate application and profit. Another handicap may be a shifting policy which in times of financial stress sacrifices first as an unnecessary luxury the research which in the long run may afford the best means to stability and continuous profits. From the public standpoint the results of investigations by industry may not be made available except after a long period of years.

6. RESEARCH INSTITUTIONS

Some of the research institutions in the United States have already undertaken a limited amount of forest research. In economics the National Institute of Public Administration, which obtains its funds partly from an endowment and partly from consulting fees, investigates the economics of public administration with especial reference to finance and taxation. It has recently made a partial study of forest taxation in New York.

Similarly the National Industrial Conference Board, which parallels in the industrial field the work of the National Institute of Public Administration in the public field, has recently made an inquiry into forest taxation in Wisconsin. The recently formed Institute for Research in Land Economics will probably sooner or later concern itself directly or indirectly with forest land as an important phase of the land problem of the United States.

The Mellon Institute is interested in industrial research, and in forest products has so far undertaken problems of box container construction, pulp and paper manufacture, etc. This Institute, which is connected with the University of Pittsburgh, is partially supported by a general endowment. Research is conducted under industrial fellowships upon projects in each case agreed upon with the donor.

A number of botanical gardens are now engaging in some phase of forest research. The New York Botanical Garden is conducting botanical explorations, is reported to be working on one problem in genetics, and is also cooperating in an investigation of physical site factors of some forest types with a number of forest schools. The program of the Brooklyn Botanic Garden deals with some of the ecological phases of forest development and also with some of the forest diseases. Some research is also under way at the Shaw Botanical Garden at St. Louis. Experimentation relating to forestry at most of these institutions could undoubtedly be expanded with advantage, but the trying out of a large number of forest trees outside of their natural ranges is of value even though nothing more is attempted.

The Carnegie Institution of Washington includes in its studies of plant life several comprehensive investigations into the ecology of range, chapar-

ral and subordinate forest vegetation. For a number of years it has also provided for dendrographic studies of tree growth. It has under way at the present time an investigation of sap pressure and movement, on the physical properties of sap, of climatic cycles and tree growth, and of the root development and root functions of the redwood.

The Eddy Tree Breeding Institute, recently established in California, has already initiated comprehensive investigations of the character which its name indicates.

The object of the Tropical Plant Research Foundation is to promote and to conduct research on plants and crops in the tropics, including forestry. It is interested in the entire scope of forestry, from the growing of timber to the utilization of the product.

All results secured by the Boyce Thompson Institute for Plant Research on plant physiology and related subjects will be of direct or indirect value in an understanding of tree functions and growth.

What research institutions can do in forest research will depend upon many conditions such as the character of the institution, the obligations which it has already assumed, and its financial resources. Many of these institutions can make valuable contributions to various classes of forest research. Possibly one of their chief handicaps will be a tendency to sporadic investigations without a very close relationship to forestry problems or forest management.

THE AGENCIES NEEDED IN A NATIONAL PROGRAM

An essential part of a national program of forest research is as specific an indication as possible of the organizations needed to carry it out. Whether those recommended by the Committee are adequate for the purpose intended can be better judged if some of the considerations previously discussed, which indicate how large our forest research organization should be in the aggregate, are summarized briefly, along with some additional facts.

1. A TEN-YEAR NATIONAL BUDGET

It has been shown that research is far superior to trial and error in obtaining the technique necessary for the solution of the timber supply and forest land use problems of the United States. This is true of every phase or class of forest research. The discussion which led to this conclusion brought out the magnitude, complexity, and urgency of the national requirements in forest research.

It showed, for example, that, large as our acreage of forest land now is, and it constitutes one-fourth of our land area, we shall probably have to deal in the future with an area even larger. The current enormous drain on our forest resources, which is well towards half of the total world requirements, promises to be even larger in the future if the timber can be made available, and this despite the fact that we shall unquestionably utilize a considerable percentage of the material which we now waste. The waste alone is nearly double the total wood requirements of the second largest wood-using country in the world. The complexity of the task is indicated by the necessity of developing a silvicultural practice for by far

the richest temperate zone forests in the world in number of species, and this problem is further complicated by variations in climate, soil, topography, etc., over an area continental in size.

The urgency of the forestry and hence of the forest research problem grows out of a drain on our timber supplies exceeding replacement in new growth by at least four times, and still largely centering upon virgin forests already reduced to one-sixth of their original area. Already the country is unmistakably in the first stages of a timber shortage. But it will probably require fifty years or more to get a program of intensive forest practice under way on anything approaching the national scale which will be necessary to meet our full requirements. Expenditures by all agencies in the United States on forest administration, planting, protection against fire and similar activities now probably total in the neighborhood of $20,000,000 annually, with about one-half from the Federal Government. These expenditures are increasing rapidly. Research is urgently needed to insure maximum returns on every dollar spent.

The outline of research problems in a national program (pages 22 to 147), most of which are in part or altogether unsolved, affords from still another point of approach a conception of the magnitude and the complexity as well as the urgency of the task in forest research, and it is impossible to foresee much of the work necessary in the future. Many of the investigations must be tried out under practically every different set of soil and climatic conditions in the United States in order to be of greatest value in actual practice. This is true of methods of cutting and of various cultural operations. It is equally true of many of the problems of forest fire protection, of prevention and control of fungus and insect attacks, of the production and use of forest range, and of the problems connected with wild life. Because of their great differences in properties our 180 commercial tree species are of the greatest value in furnishing a wood suitable for practically every requirement, but this necessitates an enormous volume of research on properties and most effective utilization.

The problem of using our forest lands for growing timber is comparable in magnitude with the agricultural problem. The area of improved agricultural land, including that in crops and humid pastures, is now only slightly greater than of forest land. An agricultural economist recently estimated that the present area of forest land in New York would eventually be increased 50 per cent by the addition of marginal lands hitherto devoted to agriculture. If such increases materialize they will be offset in part at least in other States, but such predictions are the basis for the belief that we shall have a larger area in the future for the production of timber crops than at present.

Our forest industries as a group rank about fourth among the industrial groups of the United States. The capitalization of the major forest industries alone now exceeds $3,600,000,000, exclusive of forest land and stumpage worth at least $10,000,000,000 more. They produce annually a product worth nearly $4,000,000,000 at the factory. The permanence of these forest industries depends absolutely upon a continuous supply of wood, and the growing of such supplies depends equally upon forest research. Wood, moreover, is only one product of the forest. Indirect influences such as the regulation of streamflow and the prevention of

erosion, which must likewise be permanent, are sometimes regarded as of equal or even greater importance.

Ample supplies of a highly desirable, if not absolutely necessary, material such as wood, the economic and social benefits rendered by productive lands, and the permanence of profitable forest industries, are things which we cannot afford to lose from our national life. Their absence would constitute a great national handicap. Their presence will be one of the large factors in our permanent industrial supremacy and economic and social well-being. Without research the practice of forestry which alone can bring all of these things will be very greatly retarded or in large measure ineffective altogether.

A better idea of the funds required to put forest research on a reasonably adequate national basis may be gained by a consideration of those expended in agriculture and other research which has been more fully developed. The Federal Government supports a number of agricultural experiment stations directly and makes large contributions to others maintained in cooperation with the States. Federal contributions to the latter are now increasing by $480,000 a year, and under existing law culminate in the fiscal year 1930 with $90,000 to each State, making a total of $4,320,000 for the entire country. The States in 1924 appropriated $6,115,027 in amounts ranging from $783.65 for Nevada to $597,575 for Ohio. The total staff of these stations was 2,385 people. The total Federal expenditure on agricultural research is about $12,000,000. Expenditures by both the Federal Government and the States now total, therefore, from $18,000,000 to $20,000,000. This expenditure is concentrated very largely upon the 503,000,000 acres of improved agricultural land, an area but little larger than the expanding area of forest land.

Expenditures in industrial research by the American Telephone and Telegraph and associated companies, the group which constitutes the Bell System, affords an indirect but further measure of what is justified in forestry. This in December, 1925, was reported at $10,000,000 a year. Research some 50 years ago gave birth to the first telephone and is directly responsible for the 17 million or more now in use in the United States alone. One investigative achievement, which since 1892 has made feasible the increase from 100 to 3,000 in the number of pairs of wires in a single cable, is reported to have saved the Bell System $100,000,000. Such results as this have dictated a $10,000,000 research budget and the employment of some 3,000 scientists, engineers, and technicians for investigations by a single corporate group.

A report compiled in November, 1925, by Paul E. Holden of the Department of Manufacture of the Chamber of Commerce of the United States on cooperative industrial research states, "In fact, some time ago a statement from one admittedly in a position to judge placed the amount expended annually by American manufacturers in the conduct of laboratory research alone at $35,000,000. Unquestionably this figure is well on the conservative side. In addition this same authority places the annual savings to American industry from research at one-half billion dollars."

Morris Holland states in a paper on "Industrial Research in the United States," delivered in July, 1924, that the funds annually spent for that purpose in the United States on which authentic data are available are approximately $75,000,000. He gave also the approximate expenditures

for research of a number of industrial corporations, including the General Electric Company, $3,000,000; the DuPont Company, $2,000,000; the General Motors Research Corporation, $1,000,000; the Goodyear Tire and Rubber Company, $1,000,000; the Eastman Kodak Company, $750,000.

Current annual expenditures for forest research in the United States are known only in part, but probably do not exceed $2,600,000. They include approximately $1,400,000 by the Federal Government, of which in excess of 90 per cent is by the Department of Agriculture. The States probably add about $200,000 in the State executive departments, State universities, and agricultural experiment stations. Endowed institutions and universities may add another $100,000. This leaves about $900,000 for industrial corporations and associations, and private owners, of which more than half represents expenditures by the pulp and paper industry.

In the light of these figures as well as from the consideration of the existing situation in forestry and in forest research in the United States, the Committee believes that an expenditure by all agencies in the United States of $9,000,000 to $12,000,000 annually by the end of the next decade would not be excessive. Ten years is selected because it is about the maximum time for which it is possible to go with satisfaction in setting up specific objectives in the present status of our research development. In ten years the $20,000,000 to $25,000,000, probably now expended by all agencies in agricultural research, will undoubtedly be materially enlarged. The $75,000,000 which now goes into industrial research of all kinds promises also to be very materially greater. When a single corporate group like the Bell Telephone System already expends $10,000,000, it would not be unreasonable to look forward to regularly increasing expenditures in forest research which at the end of a decade would reach from $9,000,000 to $12,000,000. It is not unreasonable for work on problems involving one-fourth of our total land area, the permanence of our fourth group of industries, the supply and effective utilization of one of our most important commodities, and of a number of lesser commodities.

The committee is well aware that there are many difficulties in the way of an increase from $2,600,000 to $12,000,000 or even to $9,000,000. A part of this difficulty will be in the education of the forest industries to a full understanding of the part that research ought to play in their activities. A part will be public education which must then be reflected in both State and Federal legislative action. A part will have to be in obtaining enough capable and adequately trained men, which in itself may slow down the entire research development unless it is provided for. Nevertheless the committee believes that the national budget indicated is needed for the development of forestry, and that the American people can meet the situation if they once decide that it is for their best interest.

The committee is able to indicate only approximately what proportion of the national expenditures for forest research might be borne by industrial agencies, the States, the Federal Government, and endowed institutions, respectively. In assigning the tentative totals indicated below, it has obviously been necessary to take into account the fact that forest research is more fully developed by the Federal Government than by other agencies, and that it requires a period of years to get work under way. Federal

expenditures at the end of a decade will possibly, therefore, be proportionally larger than will ultimately be necessary. The committee believes that the division at the end of ten years might be approximately as follows:

Industrial agencies	$2,000,000	to	$3,000,000
All State agencies	2,000,000	to	3,000,000
The Federal Government	3,000,000	to	4,000,000
Endowed institutions	2,000,000	to	2,000,000
Totals	$9,000,000	to	$12,000,000

2. MORE RESEARCH BY INDUSTRIAL AGENCIES

Some of the reasons why private owners of forest land, and the industries which manufacture and use forest products, should contribute heavily to forest research, should be considered even though they seem fairly obvious. Approximately 370 million acres, or four-fifths of our forest land, is now in private ownership. Two hundred twenty million acres of this is in commercial holdings, many so large that the owners should be expected to solve at least a part of their own problems.

The manufacture and distribution of forest products is all in private hands. Many concerns are too small to engage in the research necessary for highly efficient operations, but many are large and have obligations which are now being met only in small part.

One of the most effective weapons at the disposal of the lumber and other forest industries which are now fighting the competition of other materials is the research which will show where wood is the most satisfactory and cheapest material, and how it should be handled and used. The competitors of wood by using research force similar action upon the forest industries. Just as in all other forms of industry, research in the manufacture of forest products offers the opportunity for cheaper and more effective methods and processes, the reduction of waste, and hence a competitive advantage in price and quality. It offers the opportunity to exclusive rights through patents for improved processes and superior products. The private owner cannot depend upon the Federal Government, States, and universities for all the research he will need. Such organizations cannot be created or developed rapidly enough.

The $2,000,000 to $3,000,000 annual contribution to the national forest research budget at the end of a decade by industrial agencies can be made in several ways. Research staffs can be organized. Consulting experts can be called in periodically. Contributions can be made as cooperative funds to research institutions at universities or to State organizations or to the Federal Government, practically all of which will continue as at present to be seriously hampered by lack of funds. Research organizations may be supported in industrial associations from proportional contributions. A $3,000,000 contribution to forest research by industrial agencies would mean an increase of $2,100,000 over probable present expenditures.

3. MORE RESEARCH BY STATE ORGANIZATIONS

The States should make a large contribution to forest research because of their expanding ownership of forest land which has already reached about 5½ million acres in State forests alone, and about 5 million acres

more in other holdings. In addition practically every State has its local forest problems which it cannot expect the Federal Government or any other agency to solve except in small part. These include the local problems of unorganized small owners unable to support research except through their contributions to the public taxes. The reasons for a substantial contribution by the States are much the same as in agriculture, and in fact the management of the farm woodlot is in one sense a promising but largely undeveloped form of diversified farming.

There are no phases of forest research in which most of the States are not directly concerned: forest management; protection against fire, insects, and fungus diseases; forest influences; forest range management; wild life and recreation; the utilization of wood and other forest products; and forest economics. Accordingly in many cases a number of different State agencies may logically contribute to the $2,000,000 to $3,000,000 a year which the committee believes the States should be expending on forest research by the end of another decade. In some States each of the executive departments responsible for forestry, entomology, pathology, wild life, and agriculture have research obligations which are only rarely being met.

State universities and State agricultural colleges, even though they contain no forest schools, can and should be engaged in one or more phases of forest research. What most if not all the forest schools in such institutions need are larger faculties, not so much for instruction as for investigations. It would be an excellent thing if all such forest schools could have at least one man, and more if possible, with full time or practically full time available for research. Most need more money for the expense inevitably connected with effective research, for the establishment and maintenance of experimental and demonstration forests, for forest products and other laboratories, and for travel.

In States with appreciable areas of forest land the agricultural experiment stations should as the barest minimum have at least one investigator whose time is available for forest research, and many States should have much larger organizations. The opportunity of the State stations to do such work is increased by the Federal grants which will total $90,000 each in a few years.

The political subdivisions of States, counties, townships, and municipalities have already begun to acquire forest lands in a surprisingly large number of cases. The total area in such forests and parks has been reported at nearly 700,000 acres. Large ownership should carry with it a responsibility for a reasonable amount of forest research.

A $2,000,000 to $3,000,000 annual contribution from the States, including their political subdivisions, means an average of from $40,000 to $62,500 from each of the 48. No State, even those without appreciable areas of forest lands, is without its forest problems, but because of the very unequal distribution of forest land, and other phases of the problem, the expenditures by the States will vary within wide limits.

Definite plans or objectives in organization and finances are suggested as a desirable and effective means of developing forest research on a sound basis and with sufficient rapidity to meet requirements. This in many cases might involve an understanding as to division of responsibility between different State agencies. The committee from the very nature

of its study obviously found it impossible to attempt detailed plans for any individual States.

4. MORE RESEARCH BY THE FEDERAL GOVERNMENT

The Federal Government already makes a relatively large contribution to forest research, and a question may justly be raised concerning the obligations of the Federal Government which would justify any large increases.

Many phases and characteristics of the forestry problem of the United States are interstate or national. Several Middle Western Prairie States have practically no forest land. Many more, including even such States as New York and Pennsylvania would find it impossible to produce all the timber they need even now if every acre of their forest land were intensively managed. Chicago, New York, and in fact nearly all cities are large and important consumers of lumber, paper and other forest products. An excess of timber must therefore be grown in some States and regions for less fortunate sections. Highly specialized products such as cypress of the extreme South, and the redwood of the Pacific Coast, will have to be grown in limited areas for the entire country. States like Washington and Louisiana, which will be among the few which can grow more timber than they need, can not therefore be expected to pay for all the research necessary for highly intensive timber growing when other States and regions will benefit largely.

Streamflow regulation is equally an interstate and national problem. Floods, erosion, and silting often damage and proper regulation will aid States and regions far outside of the forested regions in which the streams have their source. Federal control of navigable streams carries the obligation to keep them navigable. The States with the largest areas and the more highly productive forest land, therefore, can not in justice be required and in many cases cannot in fact afford to pay the entire forest research bill.

Timber growing has much in common with agriculture from the standpoint of Federal contributions to research. Nearly one-third of the total forest area is in farm woodlots, representing a large number of small owners. The same reasons exist, therefore, for Federal aid in timber growing as in the growing of farm crops, where already it totals several millions of dollars a year.

Forest diseases have critical regional and national aspects. Epidemics such as the spruce budworm, the chestnut blight, the white pine blister rust, know no State boundaries, and in fact extend into several forest regions. They are national afflictions which, through the loss for which they are responsible, concern all the people of the United States even beyond the boundaries of the regions in which they occur. They have their international aspects also. The white pine blister rust was necessarily studied in British Columbia by the Bureau of Plant Industry in order to protect the forests of several western States, and similarly the Douglas fir canker was studied in Scotland.

Everyone uses wood directly or indirectly, regardless of the accident of residence. Many phases of better utilization and waste prevention are national problems along with timber growing. The multitude of small manufacturers and small users, including farmers, involve exactly the same considerations as in agriculture from the research standpoint. The

nationalization of our pulp and paper manufacture, thereby relieving overcentralization in two regions, is merely one of a large number of problems which are national or regional, or both.

In a number of forest research questions, centralized leadership is highly desirable, if not absolutely necessary. Although most forms of forest taxation are State and local community functions, national leadership is necessary for pronounced progress. Great difference in tax laws might seriously handicap or benefit competing owners in different States and the lack of any other suitable agency practically necessitates Federal leadership. For successful completion, regional surveys or a national forest survey would require the cooperation of a large number of agencies, including thousands of owners, numerous industrial associations, many States, and possibly more than one Federal agency. The Federal Government alone could successfully assume leadership in such a task.

Still another reason for a liberal Federal support to forest research is the direct ownership and management of about one-sixth of our forest area in the National Forests, plus a large additional area of woodland, chaparral, and untimbered range lands. These are distributed in practically every forest region and include many of our forest types. The National Forests have their own important problems of forest management, protection and utilization, range management, wild life management, recreational use, and finally, of forest economics. Federal forests should for one thing make the maximum cash returns to the people of the United States, and for another, become demonstration areas and models for State and private practice. Neither is possible without a large program of research which the Federal Government can expect no one else to carry.

The United States has an almost equally direct obligation for the 5 million acres or more of forest lands in the Indian Reservations. These lands are administered under somewhat the same general plan as the National Forests, and there is the same need for forest research of various kinds as a basis for timber growing, protection, and utilization.

The Federal Government must in part make its contribution to the progress of the national forestry movement through the management of the National Forests and the smaller forest area on the Indian Reservations, and through the acquisition of a much larger area of forest land. It is absolutely out of the question, however, to expect the American public to assume the entire burden of purchasing the additional area of forest land required to grow all of the timber for national needs. A large part of the effort must, so far as we can now foresee, be left to private initiative.

But private initiative must be encouraged. It is being encouraged by the Federal Government under the Clarke-McNary Act, which among other things authorizes Federal appropriations for protection against fire to be expended by the States in cooperation with private owners under general Federal supervision. This Act authorizes an appropriation also for the distribution in cooperation with the States of forest tree seeds and seedlings to farmers. It is under still another provision that the Forest Service is now investigating forest taxation for the country at large. Authoritative information on forest management, protection, and utilization which can be obtained only by research, is a thoroughly effective means of encouraging private initiative. Research, moreover, is one of the cheapest

forms in which the Federal contribution to the national timber supply and forest land use problem can be made.

AN ORGANIC ACT NEEDED FOR THE UNITED STATES DEPARTMENT OF AGRICULTURE

The forest problem of the United States is at bottom one of land use and of products of the land. Wheat, corn, domestic livestock, and wood are equally products of the land. It is for this reason that the various phases of forestry and hence of forest research are largely a function of the United States Department of Agriculture.

The Department of Agriculture, like practically all other organizations in the United States, has been seriously handicapped in its forest research by wholly inadequate appropriations. Uncertainty as to future appropriaitons has made it difficult or impossible to encourage advanced training for forest research by students, has unsettled research programs, and has made it exceedingly difficult to carry out in an ordered way a constructive plan of development.

Ample provision is required for undertaking a big national task in a big national way; in fact something like a scale commensurate with that for agricultural research. Such provision should take advantage of all that has been done in the organization of forest experiment stations, the Forest Products Laboratory, and other research units, and build on that. The Committee knows of no more effective manner of insuring the funds necessary for a program of this magnitude than through an Organic Act. Such an Act should round out the more or less scattered legislative authority of the Department and authorize appropriations sufficient for the next ten years. An Organic Act for the Department of Agriculture is the first development of outstanding importance which the Committee recommends in a detailed way. Either an entirely new and distinct act, or an amendment in essentially the same form to the Clarke-McNary Act, might be equally appropriate and effective.

Authorizations in an Organic Act for annual expenditures by classes of forest research should be approximately as follows:

A national program of regional forest experiment stations to cover silviculture and protection against fire, Forest Service	$1,000,000
Forest pathology (largely in cooperation with the Forest Experiment Stations), Bureau of Plant Industry	225,000
Forest entomology (largely in cooperation with the Forest Experiment Stations), Bureau of Entomology	225,000
Forest fire meteorology, Weather Bureau	50,000
Forest products, Forest Service	1,000,000
Tropical woods, Forest Service	50,000
Grazing research, Forest Service	275,000
Wild forest life, Biological Survey	75,000
Forest economics, Forest Service	250,000

In addition, provision should be made for special undertakings such as a forest survey. Provision might be made by lump sum authorization with the idea of completing the work in the shortest possible time. A forest survey is such an enormous undertaking that it could not be done effectively without a lump sum Federal contribution of at least $3,000,000

and the assurance of very large cooperation from States and industrial interests. As a possible alternative to a lump sum authorization the annual item for Forest Economics might be increased by $250,000, to a total of $500,000. This would necessitate somewhat slower progress and hence require a longer period of years, but on the whole would probably permit an equally effective survey. Further suggestions as to provisions which might be incorporated into an organic act for the Department of Agriculture are outlined in the Appendix.

OTHER FEDERAL DEPARTMENTS AND ORGANIZATIONS

The committee is making no attempt to outline detailed research programs which should be undertaken by other Departments and Federal organizations, and the expenditures which each program would involve.

The activities of the Department of Commerce would rank second to those of the Department of Agriculture. The regular decennial censuses of forest products and the biennial censuses of manufactures are large undertakings in themselves and now cost approximately $220,000 and $65,000, respectively. It has been pointed out that considerable data in addition to those now being obtained would be of great economic value. Other bureaus of the Department of Commerce, such as the Bureau of Standards, and the Bureau of Foreign and Domestic Commerce, will obviously undertake investigations on an enlarged scale and approach some of the problems of the forest industries from the commercial side.

The Treasury Department, the Tariff Commission, the Federal Trade Commission, and the Interstate Commerce Commission will necessarily from time to time make investigations touching upon those phases of the general forestry development which fall under their respective jurisdictions.

5. MORE RESEARCH BY ENDOWED INSTITUTIONS

UNIVERSITIES

The requirements of endowed universities with forest schools are similar to those of forest schools in State universities or agricultural colleges. Larger faculties are needed, partly for more effective instruction but chiefly to permit more time for research. Wherever possible such schools should have a number of men with full time or practically full time available for research. They should have ample provision for research fellowships. Experimental demonstration forests should be acquired or enlarged. When properly financed such forest schools can render a very large service in the development of forestry through research along specialized or even general lines.

In other departments of endowed universities with forest schools, and likewise in universities which do not contain forest schools, there is still a very large opportunity for faculty or graduate student or fellowship research on a wide range of forest problems. Many such universities give instruction in some or all of the following sciences: Botany, plant pathology, plant entomology, zoology, bacteriology, physics, chemistry, engineering, geography, and economics. All of these afford a large number of forest problems on which insufficient or no work has been done. If such

institutions will encourage research on forest problems they can in the aggregate contribute materially to our progress in forestry.

RESEARCH INSTITUTIONS

Several research institutions such as the Carnegie Institution, the Mellon Institute and the Boyce-Thompson Institute, already include in their investigative field one or more phases of the forestry problem. The field covered by such institutions should be broadened and the number should be increased. All such institutions can be assured that almost anything in forest research which they undertake will be of benefit directly or indirectly to forestry, and hence to the public welfare.

A FOREST RESEARCH INSTITUTION

Why It Is Needed

Something in addition to all of the organizations discussed is probably needed, however, to round out completely the national structure of organizations and institutions for forest research. Many of those which now exist depend on Federal or State appropriations, and in this period of high taxes even the most urgent constructive work is being provided for inadequately. While development in all such agencies must be as rapid as possible, it will necessarily be slow in comparison with national needs. Similarly expansion in the attack on forest research problems will be far too slow in endowed universities and similar institutions. Needs in forestry will have to compete with those in the whole realm of instruction and research, and at best the funds available will be far too small. The activity of industrial agencies is still small and even under the most favorable conditions which can be anticipated growth will be far too moderate to meet more than a small part of their own requirements.

Unless some additional provision is made the result will be that many lines of forest research will suffer for years to come and this will retard the general progress of forestry. Chief among these lines will undoubtedly be the classes of fundamental work which require for their consummation long periods of years, personnel of outstanding ability, expensive equipment, and which even under these conditions can make no definite and early promise of results, or of results which can be applied. Some provision is urgently needed, therefore, to insure an adequate attack on such fundamental problems. It is believed that an endowed Forest Research Institution warrants the most serious consideration as one effective means to meet this need. In addition it can serve as a stimulus both to new work and to increased efforts by all other agencies, and in short round out the national structure of forest research organizations.

What It Should Do

Such an institution should first and foremost be prepared to undertake, with its own staff, those long-term fundamental projects which no other organization can undertake effectively. The projects so selected should constitute a balanced, well-rounded-out group at the heart of the several chief divisions of forest research outlined in this report—forest management, forest protection, forest influences, forest products, and possibly forest economics.

One of the serious handicaps of all except possibly the most recent

fundamental forest research of Europe is its scattered and fragmentary character. One investigator examines a single narrow phase of tree growth or requirements. It may be the change in stated food substances in the tree upon the approach of winter for a single species, light intensity and photosynthesis in one or two species, the use by a single species in one locality of diffused light, nitrogen fixation by a very limited number of bacterial organisms, or some local phase of soil acidity. Each investigator works independently of all others. Exceedingly valuable information results, but fragmentary, full of gaps, and difficult, or impossible of correlation. It furnishes, for example, in the aggregate, a part of the soil requirements on one species in one locality, a part of environmental light relationships of another species somewhere else, an isolated phase of the physiological activities of a third species.

A Forest Research Institution could very profitably attack fundamentally in a well-rounded-out program the crucial points of the entire complex of requirements and developments of the forest type or types, centering at a very limited number of representative places, at least to begin with. Only such an attack can bring out fully the interrelationship between climate, light, soil, subordinate vegetation, and the competition of tree species, and the effect of all upon physiological processes, reproduction, growth, and finally, the volume and fundamental physical and chemical properties of the wood product. It is not enough that each of these fundamental questions should be studied exhaustively. Each must be studied exhaustively in relation to all of the rest, and at the same time and place; in fact this is the only way any one can be studied exhaustively.

Never in the history of forest research have the personnel and facilities been available for such coordinated attacks. Were they possible the results would be invaluable.

For the United States, the institution would supply technique, preliminary results, and final results to other agencies on some of our most difficult and baffling problems, and the results could then be checked locally by additional research and adapted for practical application in the development of a sweeping, comprehensive, national program. When results have been carried to a certain point at central field stations it may be necessary in special cases to check them under other forest conditions in different parts of the United States to determine their correctness and to ascertain variations. It is conceivable that there may be a limited number of special problems which in the first instance would have to be undertaken at locations away from the central stations. Plans for the institution should be sufficiently flexible to allow for variations of this character when the work would be benefited.

The institution should also be prepared to subsidize carefully selected projects at other institutions to be selected with equal care. In every case the men who are to do the work should be taken into account. Progress on important work undertaken by competent men is often greatly hampered by lack of funds. In many such cases relatively small subsidies for a few years would greatly stimulate the progress of research and with it the general development of forestry. Still further, subsidies properly placed and controlled might be made to stimulate materially the amount of work undertaken by a large number of institutions in the United States which are now attempting nothing at all on forestry. Ordinarily such

subsidies need not be permanent. Work once started could gradually be taken over in most cases by the parent institution, and the central forest institution could then withdraw.

A Forest Research Institution might also permit representatives of other institutions to do special work at its own field or other laboratories, independently or in cooperation with members of its own staff. While the objective should be primarily the solving of research problems, provision of this character should aid in the training of highly competent men. Facilities of the sort which a Forest Research Institution should have would result in a gradually increasing number of requests for cooperative work from men at other institutions.

The institution should obviously be prepared to disseminate the results of its own investigations through publication. If publication could be liberalized to take care of signal contributions by men in other institutions where other means were not available, it would undoubtedly promote forestry. This provision might occasionally go so far as to include the translation and publication of especially noteworthy results in foreign languages.

An institution of this character should be able as a minimum to cover directly and through subsidies a selected group of fundamental and national problems. Canadian and American problems merge, so that an international charter would have distinct advantages. The United States is more directly interested perhaps in the development of forestry in the tropical hardwoods of the West Indies and Central and South America than in those of any other foreign countries except possibly Canada. It is to the tropical forests that we shall undoubtedly have to look for our hardwood imports until American hardwood forest lands can be made fully productive and the first crops mature. Possibly, therefore, tropical forestry and tropical forest products should in time have a place in the research program of such an institution. It should be possible, however, even though programs are concentrated on forest problems of the United States or of the Americas, to send members of the staff of the institution to any part of the world where the results would justify this action.

How It Should Be Organized

The institution should preferably have as its single objective, forest research as a fundamental aid to forestry in the United States, or the Americas or possibly all countries, and it should accordingly be independent of other research institutions. Absorption into another institution with many lines of work under way might defeat or retard the fullest consummation of this objective. Furthermore, trees and forests are essentially different from all other forms of plant life in the long time required to reach maturity. Volume, growth, and yields for trees and forests present problems which have no parallel in other biological research. Forests differ greatly from agricultural crops in both the nature and amount of cultural operations which are feasible. Forest research must deal primarily with plant communities or forests, not with single plants. Forest research must therefore in the main have an entirely different technique and background from that of other research. It undoubtedly could be best developed in a distinct organization.

Precedents from research institutions already established in the United

States or elsewhere should be helpful in formulating plans for the organization of a Forest Research Institution. The institution might have a single governing board similar to that, for example, of the Carnegie Institution, made up of a carefully selected group of men who have attained national distinction in various activities. Or it might be preferable to follow the plan of the Boyce-Thompson Institute for Plant Research in which a board of directors is charged with the maintenance and care of the endowment and property, and a board of scientists acts in an advisory capacity to the director of the institution on the organization and management of the institution and in the selection of the scientific staff. Or as a third alternative, it might be possible, as in the Tropical Plant Research Foundation, to vest the administration in a single board with proper representation of both business and scientific men. One of the prime essentials as to representation on a board directing the activities of an institution charged with forest research, which is a question of vital public concern, would be adequate representation of the public interest. Beyond this it would probably be best to give both scientific and business interests a voice.

Such a Forest Research Institution will require both field stations and laboratories. In their location the committee believes that the general principle of the highest feasible concentration of the different lines of forest research should be followed. This alone will insure the desirable if not essential contact between the scientists investigating different problems, and concentration of attack on all the fundamental phases of forest life environment and development at the same time and place, and hence the most thoroughly coordinated and effective effort.

With the maximum of concentration, which might mean three main field stations and laboratories or possibly only two for the entire United States, and with possible later and additional provision for Canada and the tropics, the principle of flexibility should also be recognized. Members of the institution staff might after working out fundamentals under one set of conditions find it advisable or absolutely necessary to work for relatively limited periods in other parts of the United States either independently or in cooperation with other research institutions. They should, however, return to a central laboratory or station as soon as the work permits.

One of the principal features of each main field station should be a forest tract, preferably owned by the institution but possibly leased for a long term. Each forest should be representative of as large a section of the country as possible, and contain as many as possible of its forest types. An area of from 20,000 to 30,000 acres in each case would probably not be too large. Incidental to research, this forest should be managed intensively. The forest should primarily afford facilties for research. It should also be a demonstration area of exceptional value. One of its most important functions, however, would be to serve as a background. Such forests would tend to prevent research purely for its own sake and to keep in mind the ultimate objective, that of land use in the growing, protection and utilization of forest crops. Each main field station should be supplied with suitable laboratories in order to afford the closest possible contact between research in the woods and in the laboratory. It might be possible, however, to concentrate at one of the laboratories a large part of the work of this class.

The principle of concentration is all the more justified when a Forest Research Institution is considered as one unit only in the national research structure. Fundamental results obtained under the sets of conditions which exist at a central location, or at least of the research technique developed, could often be adapted to a wide range of local conditions in many parts of the United States by a large number of research institutions, both public and private, already on the ground. A Forest Research Institution could in other words perform its greatest service by leading the way and leaving to other institutions the working out of local adaptations and the practical application of general laws.

How It Should be Financed

Financial provision for an institution of this character must be governed by the size, complexity, and urgency of the problems which it is to undertake. Its field would still be continental even though it confined its operations entirely to the United States. The work should be developed as rapidly as competent men can be obtained. The financial resources should be sufficient to pay salaries which would draw the ablest, best-equipped investigators regardless of their present connections. By subsidies and otherwise the work at a large number of institutions should be stimulated to a vastly increased scope and scale. A program of this sort could not be adequately undertaken with an annual income of much or any less than $1,000,000, and it might require after the first decade a considerably larger sum. This income to be of the highest usefulness should be stable. An endowment alone would seem to meet all these requirements.

The estimate of $2,000,000 annual expenditures for forest research in 10 years by endowed institutions is made up of $1,000,000 for a Forest Research Institution and an equal sum from endowed universities and other endowed institutions.

6. A NATIONAL STRUCTURE OF RESEARCH ORGANIZATIONS

A Forest Research Institution and the research organization provided by an Organic Act for the United States Department of Agriculture are the two outstanding and detailed recommendations of the Committee for enlarged forest research organizations in the United States during the next ten years. Together with materially enlarged activities by the States, by industrial agencies, and by endowed institutions in general, for which the Committee could not make detailed recommendations, they should constitute a more or less homogeneous national research structure. It should be closely enough knit to function effectively, but the different units must be independent enough to give play for individualism and to stimulate progress. There need be no serious overlapping of work among these agencies. They should be component parts of a larger whole. There will be ample room for all of them, and if anything approaching the organization program outlined is attained by 1936, it will be found that work has not even begun on large numbers of important problems.

Each research agency or class will make a more or less distinctive

contribution in this research structure. Private owners and industry will concentrate chiefly on their own localized problems and on the application of more general findings to their own forest conditions or industrial requirements. The States will necessarily work in part on somewhat more generalized problems but ordinarily not beyond those peculiar to their own territory. An important State function will be to serve large numbers of small owners who cannot be expected to support forest research except through taxation. State institutions should also work on those fundamental problems which underlie their own needs. The Federal Government must attack regional, interstate, and national problems, local problems before local agencies can be stimulated, and many phases of fundamental work. The National Forests alone place a heavy obligation for research upon the Federal Government. Endowed institutions will in most cases work on selected problems or some phase of fundamental research. This will leave for a Forest Research Institution those long-term, costly, fundamental problems which no other agency can undertake. Since the general fields which these agencies will occupy obviously overlap somewhat, means of preventing serious duplication will gradually become necessary. The most urgent need, however, will be for trained men.

TRAINED MEN

Expansion of research organizations will require corresponding increases in the number of highly trained men. Except during the past five years, or ten years at the most, there has been little incentive in the United States for men to spend the time and money required for advanced training for any phase of forest research. Of employment in which such training could be used the assurance has been small, and practically no fellowships have been available for men without the necessary means. The relatively rapid expansion of research organizations, particularly during the latter half of the decade, has therefore brought an acute problem in the lack of enough suitably trained men.

In organizations where the need for men has been greatest, and this is most true in the Forest Service, it has ordinarily been necessary to employ the best men available even though they have not always had all the advanced training which might be desired. In the Forest Service outstanding men from the administrative organization and the best men from civil-service registers have regularly and as a matter of definite policy been selected for the past decade. This, however, can be only a temporary expedient.

While a good deal of the research of the past decade has been of a preliminary character, that of the future will go more deeply into fundamentals. Accordingly it will be more and more necessary to have men with advanced training as well as men of exceptional ability. Those who have already gained experience in research and who were carefully selected to begin with should be afforded every opportunity for advanced training. The possibilities for training on the job for the right kind of men when under competent supervision are usually underrated, but regardless of this all organizations should systematically assist their men to broaden their training by return to universities or by less formal arrangements.

The Department of Agriculture follows a liberal policy in granting furloughs to its investigators to permit them to return to universities for advanced training. Special arrangements have been perfected for credit in regular departmental investigations towards advanced degrees at a number of universities. Special courses have also been arranged for investigators in Washington outside of official hours with credit toward degrees in universities of high standing. Even beyond this, however, it will undoubtedly prove advisable to go as far as possible in systematic attempts to encourage promising men already employed who have not yet had advanced training to take the necessary action to obtain it.

The Department of Agriculture, however, is only one employer of trained forest investigators. Many other organizations are already in the field and the needs of a large proportion will increase steadily or rapidly. The increase in the number of opportunities for employment on highly desirable work will in itself constitute a great incentive to advanced training, but even this will fall far short of meeting the national needs.

The situation already demands a substantial number of fellowships as one means of stimulating training, but few are available. If our forest research organizations are enlarged as rapidly as they should be we ought within a few years to be able to absorb an annual output of 50 or more men with advanced training, so that as a minimum, at least 30 or 40 fellowships would not be excessive. The fellowships should be well distributed among the different phases of forest research. Such fellowships should be available only to the best men and they should preferably be available only at the strongest institutions.

Europe can help us. Traveling fellowships for a few selected men each year would be stimulating. Combined with this plan, however, should be provision for bringing to the United States leading European investigators who could help develop investigators in all of our research institutions.

The advanced training of large numbers of men places a new and heavy obligation on the forest schools which few are now equipped to meet and which cannot be undertaken on short notice on too large a scale. It will be necessary for many of the forest schools to strengthen their faculties and to organize systematically for this new task on a much more intensive and much larger scale than at the present time. Possibly the forest schools, by dividing the field so that each can develop strong leadership in some one or few special phases of advanced training, could cover the entire scope of forest research much more quickly and effectively. Already we have reached the stage when a critical problem is to obtain men of strong mentality with training suitable for the most fundamental work, and the demands of the future along this line will become more and more insistent. The main burden of this demand will fall on the forest schools.

One prerequisite in the training of men for forest research, whether they are to be employed as economists, or as engineers, chemists, or physicists, in the study of forest products, or as physiologists, ecologists, or geneticists in the study of any form of forest life, or as pathologists, entomologists, or zoologists in forest protection, should be a broad general training in forestry. Only such training will give the background neces-

sary for well-balanced research which will keep chief objectives in mind and prevent specialties from becoming objectives in themselves.

CORRELATION AND STANDARDIZATION

Correlation of Research Programs

Several forest regions and some classes of forest research are now occupied by a single investigative agency. In other cases the number of agencies is very small. Duplication has not yet, therefore, been serious, and it still is far more important to get research under way than it is to attempt correlation. In some regions such as the Northeast, however, correlation is beginning to be important and will become more so as existing research units enlarge their programs and new agencies are organized. It is well, therefore, to have correlation begin before research policies and programs set and become difficult to change. Furthermore, active correlation ordinarily stimulates an increasing volume of research by emphasizing problems inadequately covered or neglected altogether.

Among the correlating media already in existence are the regional advisory committees created by the Secretary of Agriculture primarily to assist the Department in the formulation of the programs of its forest experiment stations, but also to exert whatever influence may be desirable in the correlation of programs and in the stimulation of research activities. Into these committees has been brought representation from various interested groups. For example, the Advisory Committee to the Northeastern Forest Experiment Station includes representation of State forest departments, agricultural colleges and experiment stations, forest schools, consulting foresters, the agricultural, lumber, pulp and paper, and box industries, and the railroads.

The Department hopes to create these committees in all important forest regions as rapidly as the conditions permit. The possibility of a common meeting ground for scientific, educational, public, and industrial groups is of the first importance in the correlation and expansion of research in forest management and protection, and in the application of results.

Sooner or later a national correlating body may be needed. It might be organized under the auspices of the Society of American Foresters, of a Forest Research Institution when it is formed, of the National Research Council, or possibly of the Secretary of Agriculture. Among other representation could be included that from each of the regional advisory committees. This might be supplemented by representation from national, scientific, public, educational, and industrial organizations.

In forest products, forest range management, and economic investigations the movement towards correlation has not as yet progressed as far. Out of the National Conference on Utilization of Forest Products called by the Secretary of Agriculture in November, 1924, is developing a permanent National Committee on Wood Utilization. While the chief objective for which it was formed was to get the results of research into practice, the Committee may offer one means of correlating and stimulating forest products investigations, and may also undertake some research itself. In forest economics far too little work has been done to justify

a national or even local correlation. With the enlargement of the work, however, the need for correlation may arise.

Standardization of Investigative Technique

A beginning has been made toward the standardization of investigative technique in the United States for a few of the conditions where it is desirable. A recently formed committee of foresters with representation from the Society of American Foresters, the Association of State Foresters, and the Forest Service is outlining uniform technique for growth and yield investigations, and hopes from its work to insure comparable future results from all organizations. Uniform methods are designed primarily for large-scale work and should not prevent clearly desirable attempts to improve methods by additional inquiry. A similar committee is being organized to outline a technique for permanent sample plots.

A further attempt by the Forest Service to formulate standard technique for testing timber for strength is now far advanced under the auspices of the Society for Testing Materials and the American Engineering Standards Committee. Its purpose is comparable results on the strength properties from tests made by any investigative agency in the United States.

As forest research grows and satisfactory technique is worked out and demonstrated, it will be desirable to increase the number of projects of this character, but the instances of technique which lend themselves to standardization will be small. Standardization should be attempted only in some cases where large numbers of measurements or tests will be made by different organizations on different species of timber, and where comparability of results will depend absolutely upon uniformity in technique.

Standardization of Products Specifications

The opportunity for the standardization of specifications for forest products is very large, but it has already been so fully covered that it need only be referred to here. It must for practically all materials rest upon investigative work.

CONCLUSION

THE ESSENTIAL UNITY OF FOREST RESEARCH

Upon superficial consideration the main phases of forest research which have been discussed—forest management, forest protection, forest influences, forest range management, wild life, the utilization of wood and other forest products, and forest economics—may seem to be related only in unessential detail if at all. For example, research into forest range management may easily be regarded as a specialized agricultural question primarily with little or no vital connection with the reproduction and growing of trees. Forest game, and more obscure forms of wild life about which even less is known, often seem to have such an indirect connection with the growing of timber or the production and use of forage for livestock grazing that it is far too easy to overlook the necessity for unified research. Research on the properties of wood, the reduction of waste, more efficient utilization, the specifications for products, may seem to be chiefly matters of industry or commerce. Investigations of forest economics may seem to deal chiefly with questions of sociology or commerce remote from those of soils, tree physiology, silviculture, or the properties of wood. Although the preceding discussion has incidentally brought out many interrelationships between both major and minor phases of forest research, the full recognition of the unity of the whole field of forest research is so vital that it necessitates special consideration.

1. THE FOREST A BIOLOGICAL UNIT

The forest is a biological unit. This is the first premise in considering the essential unity of all forest research. The best development of forest research requires the recognition of this fact as one of its most basic conceptions. Although the trees or the forest proper are only one part of this unit, foresters too often assume that they are not particularly concerned with any other form of forest life and that they need to take into account soil and light only slightly more. As our information increases it is becoming more and more apparent, however, that the many species of the subordinate vegetation, forest fungi, forest insects, wild forest life including even that of the streams and lakes, and the fauna and flora of the soil, are all interrelated forms of a single biological unit or aggregate. Many species of these various forms of life compete for food from the soil and for vital energy from the sun. In varying degree they consume or prey on each other or are dependent upon symbiotic relationships for existence.

These numerous forms of life may be in apparent balance as perhaps in a virgin forest. At times the place of one or more of them may be violently disturbed by natural forces. Man, however, is commonly the disturbing agent. He cuts the forest, grazes his livestock on the subordinate vegetation, kills off the game and wild life, or lets loose destructive fires. When one or more forms of life are disturbed, very far-reaching forces may be set in motion, which may act and interact almost indefinitely

on several or many other forms. Forest or range or game management, which in one sense are nothing more or less than premeditated disturbances of nature's balances, depend for their highest efficiency upon a knowledge of how to utilize the beneficial effects of disturbed balances and to prevent the harmful effects at least so far as the desired products are concerned.

Underlying all forest relationships are the basic substances and energy without which life is impossible. Numerous materials, nitrates, nutrient mineral salts, water, and carbon dioxide, derived directly or indirectly from the soil or the air, contribute in exceedingly complex ways to the existence and support of the trees and other forms of plant and animal life which make up the forest. So likewise does the radiant energy of the sun. The very configuration of the earth's surface is an important factor through its influence on climate and soils. Common dependence of all the forms of life upon these materials and energy, and in many cases active competition for them, necessarily in themselves relate all phases of research dealing with the forest aggregate.

Silvicultural and Range Investigations

Practically no forest exists in the United States that does not at some or all stages include a subordinate vegetation. Although we now know of only a few instances, there are undoubtedly many in which forest reproduction is aided or retarded by different species or associations in the subordinate vegetation, or vice versa. Both forms of vegetation compete for light and for moisture and food from the soil. Both affect the composition of the soil. Both aid in the prevention of erosion. Both contribute fuel for forest fires. Both furnish food for livestock, game, and insects, and serve as hosts for fungi. Various species of *Ribes* in the subordinate vegetation of the white pine forests serve as the alternate host for the blister rust and so interrelate subordinate vegetation and the forest and their management and protection.

Soils, lifeless to the naked eye, have their microscopic populations numbering millions to the gram, of bacteria, algae, fungi, and protozoa. Some of these organisms break down dead plant material into suitable and essential forms for re-use by the forest and subordinate vegetation. Others take nitrogen from the air and make the essential nitrates available for plant growth. Still others are injurious as diseases or consume foods essential to plant life. Soils may harbor larger forms of life also, such as destructive insect pests during some stages of development. The highly beneficial activities of the common earthworms have long been known. Common dependence of forest and subordinate vegetation upon soils gives a common relationship to soil life, microscopic and otherwise. Each tree and plant species reacts upon soil life in turn. Research of forest soil life or in fact of any other soil problem can hardly therefore be directed exclusively at the problems of either forest or subordinate vegetation even though that might seem desirable.

The utilization of the subordinate vegetation or forest range either by domestic livestock or game, reduces the volume of fuels and hence both the danger and the severity of forest fires. Under some conditions such utilization may take the young forest trees along with forage plants

and hence tend to prevent reproduction. In parts of the East, particularly in the hardwood farm woodlot territory of the central States, grazing may compact soils, reduce the rate of growth of the forest, and destroy reproduction. Under other conditions it may by the removal of competing vegetation create conditions which are favorable to forest regeneration. On the other hand, the age, density, and possibly the composition of the forest, the manner in which it is cut, and the disposal of slash dominate in greater or less degree the composition, amount, and vigor of the subordinate vegetation and may in extreme cases exclude it almost entirely. Research which deals with the growing and protection of timber and that which deals with the production and use of the subordinate vegetation for grazing have therefore many ecological and other problems in common, all of which can best be attacked with both objectives in mind.

Neither is it possible to separate out a single phase of the broad scientific problem underlying forest management, like physiology, and pursue it to a full and satisfactory conclusion. Such attempts in the past have greatly detracted from the value of many admirable pieces of work in both the United States and Europe.

Silvicultural and Wild Life Investigations

Wild life of the land, game, rodents, birds, and probably also that of the lakes and streams, play their part in the biological aggregate of the forest, so that we cannot ignore the far-reaching interrelationships which affect in greater or less degree both the growing of the timber and the perpetuation of the wild life. While birds are known to carry such diseases as the chestnut blight, which is rapidly eliminating a splendid hardwood from an enormous area, they are, however, a great benefit in controlling destructive insects and in the dispersion of such seeds as the eastern red juniper. Small rodents consume such large quantities of forest tree seeds that they seem in some cases to be important factors in preventing reproduction. When numerous, and especially during drought, rodents consume so much forage that the livestock industry is seriously affected, and the shortage of food leads to excessive damage to forest reproduction. It now seems as if the killing of predatory animals as a protection to domestic livestock on forest ranges has been a factor in permitting the increase of porcupines to the point where they are doing serious damage to forest reproduction in the Southwest. The relationship between predatory animals, the protection of rabbits, and successful planting in the Lake States has already been pointed out, but it is only one instance of many far-reaching relationships which are now very obscure or altogether unknown. The research which underlies game and forest management can therefore be no more distinct than the interrelated forms of life with which it deals.

Silvicultural and Forest Protection Investigations

Forest fungi are always an important and under some conditions may be a dominating factor in the biological complex which we recognize as a forest. In some cases they may determine the rotation or age at which particularly susceptible trees like the firs and incense cedar in California must be cut to obtain satisfactory yields. Many thin-barked trees are

easily wounded by fire, and such wounds permit the entrance of fungi which materially reduce the volume of merchantable wood. Fungi have an important bearing on the forester's selection of the trees for future stands. They are one of the two important factors in compelling wherever feasible the growing of two or more species in mixture as a protection against destructive attacks. In practically all forest types, fungi must be reckoned with.

Forest insect life is not a thing apart, but, whether we will or no, an integral part of the forest which we must recognize or which will in many cases defeat our purpose. An excessive abundance of jack pine stands in the Lake States following lumbering and fires which have eliminated other species have made conditions much more favorable for the jack pine sawfly. The rapid multiplication of this formerly inconspicuous insect seems to be due directly to the change in forest types which, among other things, has increased the quantity of its food and reduced the number of insectivorous birds and mammals by creating for them conditions less favorable than in forests of mixed pine. Equally important relationships of insects to subordinate vegetation exist in such ways as pollination and destructive attacks. If all the truth were known, the forest type or subordinate vegetation association is rare in which insects are not a critical factor in the biological unit. Research in forest protection which does not clearly have forest management as its ultimate purpose loses its most valuable objective, and silvicultural investigations which neglect the health of the forest are equally shortsighted.

All Investigations of the Forest

Together the forms of forest life, with their food materials and source of energy, make up an exceedingly complex biological unit. The aggregate, which after all is the forest rather than the trees alone, varies minutely or widely for every acre of forest land within the United States and even within single acres. Beyond this the balance or relationship between species and groups of species varies widely in the same area at different times.

No research as a basis for the management of any one form of forest life, whether plant or animal, or of any one environmental factor, or of any combination of either which leaves any one or more out of consideration, can be certain of obtaining the whole truth. This background of interrelationships and unity, of balances, and of the disturbed balances which constitute management, should make of the different phases of forest research not distinct lines of endeavor having independent ends of their own, such as classification for purposes of discussion or organization might seem to imply, but rather subordinate integrated parts of one whole.

This basic interrelationship and unity should be taken into account so far as the resources in men and funds will permit in the organization of research and in the formation of programs dealing with the growing and protection of the forest, the growing and utilization of the subordinate vegetation, the management of all wild life, and all forest influences. This is the fundamental basis of the organization outlined for the Federal Forest Experiment Stations. There is the opportunity for taking it more fully into account in the relationship between the Federal Forest and

Range Experiment Stations. It should be taken into account just as far as possible in both organizations and programs of all other Forest Experiment Stations.

2. WOOD A BIOLOGICAL PRODUCT

Another basic conception which should underlie the development of forest research is the recognition of wood, and other forest products likewise, as complex biological products, the properties of which are modified by the conditions under which they grow. It is a second premise in considering the essential unity of all forest research. The widely different conditions under which trees have grown in past ages have undoubtedly contributed to those differences in organs or parts and in wood which we recognize as tree species, genera, and orders. Contemporary conditions of growth which include most or all other forms of forest life and the environmental factors which constitute a forest are also responsible for those differences, great and small, which we find within wood of even a single species. For example, ash grown in the swamps of the Mississippi Delta is much more likely to be light and brash than the same species from the northern highlands.

We attempt to classify the properties of wood as physical and chemical, but actually all the properties are inextricably mixed. This is true of structure, whether it be gross as exemplified in cells and grain, or minute as exemplified in the obscure makeup of the cell walls; of strength, density, specific gravity, heat relationships, moisture relationships; of shrinkage and expansion, working and checking, and the behavior of wood in general; of working properties, electrical conductivity, chemical composition or other chemical properties, and the pulping qualities. Any one characteristic, such as the minute structure of the cell walls, influences permeability by liquids and many other properties and within wide limits. Research which attempts to select one factor and ignore all the rest is in serious danger of obtaining less than the whole truth, just as in the growing forest.

Silvicultural and Forest Products Research

The very fact that the forest as a biological unit produces a biological product, wood, gives to silvicultural and forest products research an important point of direct contact and a common background. When variation in the factors which contribute to the forest make a difference in the wood, we have the opportunity of so regulating the conditions of growth that within limits we can obtain woods of desired properties. The investigator in forest products must ascertain what properties of wood are best suited to specific uses, and the silviculturist must learn what conditions of growth, density, forest mixture, soil conditions, and light will come nearest to giving the desired properties.

Beyond this the silviculturist and the utilization expert must work hand in hand in order to obtain the conditions which will lead to the best utilization and the most profitable silviculture. Logging methods which have hitherto failed to take into account the perpetuation of the forest must be adapted to practical silvicultural requirements. In the proportion utilization is improved silviculture can become intensive. The further research goes into utilization and silviculture the more they will converge into the

field which underlies both. We shall have more and more difficulty in drawing an exact line between them. There will be more and more need for joint attacks on common problems.

The fact that wood is a biological product of great complexity in which every property and element of structure are interrelated must be taken into account in deciding upon the best form of organization for forest products research. It dictates concentration for most lines of work into a single unit in which different groups of men shall attack different phases of the same problem. Efforts can then be correlated. The same principle holds as for Forest Experiment Stations and for the same reasons. There should be the same unity and comprehensiveness of attack. This basic conception outlined was the guiding principle in the organization of the Forest Products Laboratory by the Department of Agriculture.

The gradual convergence of fundamental research upon silvical and products problems in the United States Forest Service has finally reached a stage which justifies the formation at the Forest Products Laboratory of a section dealing with biological problems. Such a section has now been definitely planned. The dependence for best solution of many of the problems of forest management upon the solution of problems in logging and utilization, is clearly indicating the need for closer cooperation between the Forest Experiment Stations and the products units in the Forest Service. These organization tendencies in the Forest Service are in themselves striking indications of the unity of silvicultural and forest products research.

3. FOREST ECONOMICS AND OTHER FOREST RESEARCH

Research in forest economics should aid in crystallizing the problems upon which other classes of forest research should concentrate. For example, when economic research points out that 80 per cent of our total paper requirements are centered on one group of species which constitute only 11 per cent of our total remaining stand, that as a result we have already become dependent upon foreign countries for more than half of our paper or its raw materials, and that we shall have even more difficulty in the future than at present in obtaining our full pulpwood requirements, research in silviculture to increase the production of this group of species is indicated. Forest products research which will increase the number of species which can be used satisfactorily is also indicated.

Research in forest economics should also determine the financial feasibility of applying the results obtained in other classes of forest research. For example, it should determine for the private owner the financial feasibility of forest management under the methods and potential yields determined by research in silviculture and forest mensuration. It should tell him what his returns in stumpage or otherwise are likely to be as well as the probable costs of the mature crop. Beyond the mere acquisition of costs this class of economic research should be constructive on such problems as forest taxation and insurance, and many phases of forest organization and administration. About the close relationship of research in forest economics with other classes there cannot therefore be any question.

If it were necessary in order to make still more conclusive the interrelation and interdependence of all of the different phases of forest re-

search, this discussion could be materially enlarged. The examples indicated above, however, are supplemented in the discussion of the research problems which occupies the greater part of this report. In this discussion constant cross references are required in order to bring out interrelationships clearly, and this in itself is an indication of the great difficulty of distinctive classification. All things taken into account, there is therefore no escape from the essential unity of forest research. This principle should receive due weight in plans for the organization of forest research, in formulating investigative programs, and by all means in the training of investigators.

PROGRESS AND NEEDS

Organized forest research in the United States is confined largely to the last 15 years, excepting dendrology and the taxonomy of other forest plants. Investigations actually began on a very small scale approximately 50 years ago, and on an appreciably larger scale about 25 years ago. Pioneer work, again excluding dendrology, was in silviculture and forest products; that on forage and its use in grazing and on forest economics is much later; that on protection against fire falls largely within the last five years. Pathology began its development as a distinctly separate entity about 1900, but investigations were not related particularly to forest management until about 1910. Investigations in forest entomology started about 1890. Even now the investigation of wild life with reference to timber production is barely beginning.

The greatest progress has been made in forest products research; the least in investigations of forest influences and of the wild life of the forest.

The greatest need for enlargement is in those branches of forest research which deal with the growing of timber crops, and it is these which in the last analysis we would need to the exclusion of all others. Forest products research should, however, reduce the drain on existing timber supplies and can be made most immediately effective in lessening the severity of a timber shortage. It can also be made to stimulate timber growing by making it more profitable, or even feasible. Comparisons of this character, however, are chiefly of academic interest because we cannot get along satisfactorily without all classes of forest research, and we know that all should be materially enlarged.

1. FOREST MANAGEMENT AND PROTECTION

Although we have made a good start in the preliminary research dealing with the growing and protection of timber crops, we have as yet largely failed to apply the technique of the fundamental biological sciences to the solution of these problems. This is less true in taxonomic studies than in any others, but the taxonomic studies constitute only a very small fraction of total requirements. The failure has resulted partly from a lack of foresters trained in the fundamental biological sciences, and it is partly also the natural evolution in a new field in which research ordinarily begins with the general and empirical and progresses into the fundamental.

The technical knowledge for a passable silviculture in possibly one-tenth of our most important forest types, with a much smaller scientific

basis in about an equal additional number, together with a reasonably satisfactory technique for nursery practice and field planting of the 15 or 16 species now most used would cover a very large part of the silvicultural field in a continent with a relatively small number of forest species and types such as Europe. The complex forest conditions in the United States, however, make our results seem much smaller than they actually are, as does also our present lack of a traditional art of forestry built upon long years of actual practice. We have then ahead of us in silvicultural research the preliminary work on a large number of forest types on which little or nothing has been done, and most of the fundamental research upon all of our forest types.

Our work on forest fires, despite its very recent beginning, has given preliminary information of great value, and what is probably more important, has served to block out at least the broader aspects of the problem. In both forest entomology and pathology much preliminary ground has been covered. The taxonomic foundation also is largely available and control methods have been developed for a few of the most serious insect and fungous attacks, and investigators are now entering the fundamental fields of ecological and physiological relationships. The latter classes of research have become infinitely more valuable because they are now regarded as phases of forest management.

Research in forest management and protection has been undertaken in greatest volume by the United States Department of Agriculture. Nine out of a proposed program of 11 regional stations for the continental United States have already been established with small initial appropriations, and the remaining two have already been authorized by Congress. The Department also conducts a considerable amount of additional work.

Other established forest experiment stations include those of Yale, Harvard, and Minnesota Forest Schools, and the Mont Alto State Forest Academy in Pennsylvania. Definite beginnings have been made towards stations by a number of other institutions. Among the State departments of forestry only Pennsylvania has a distinct forest research organization. Both Maryland and New Jersey have outlined fairly comprehensive programs. New York, New Hampshire, Massachusetts, Ohio, and Indiana are doing a fair amount of research. Quite a number of the remainder of the 34 States which now have State departments attempt some research. State universities, colleges of agriculture, and agricultural experiment stations in five States—New York, Minnesota, California, Michigan, and Connecticut—have fairly comprehensive programs. Similar institutions in nine States—Washington, Iowa, Kentucky, Ohio, Pennsylvania, Massachusetts, Idaho, Oregon, and Vermont—have somewhat smaller amounts of research under way. The institutions in about 20 additional States are attempting something.

A comparison of the status of silvicultural and protection research in other countries chiefly European with that in the United States may give a clearer idea of where we stand. Europe has a great advantage over the United States in much simpler forest conditions, in much older forest schools, in relatively large numbers of highly-trained men, and in a practice of forestry often of long standing. In actual results, however, Europe is surprisingly little ahead of the United States, and few countries lead at all.

Organized research is only about 50 years old in Central Europe, including Germany, Austria, and Switzerland, and in most other countries it has developed largely since 1900. Since the World War it has received a new impetus, especially in the British Empire and the new countries of Europe.

While European research had its beginnings at the forest schools with which in many countries it still is closely connected, the recent tendency has been to make it more or less independent of educational institutions. At first, as might be expected, college faculties selected their research projects independently and more or less at random. The tendency now seems to be to broaden the scope of the work, and several countries have rather elaborate programs, but very few, if any, have more comprehensive programs than that upon which we are now working in the United States.

In Europe and other countries, just as in the United States, the most pressing need at first has been for information that could be applied to the immediate problems of forest management. The more fundamental studies in ecology, biology, physiology, and soil science and the more intensive silvicultural investigations have generally come later. Sweden and a few other countries have gone farther than the United States with some of these fundamental studies.

Because of the emphasis upon artificial reforestation and afforestation, problems connected with seed collection, nursery practice, and planting have a prominent place in nearly all the programs. For the same reason all countries are paying much attention to exotics and most of them are going farther than the United States in the problems of seed selection and climatic races.

Studies of silvicultural systems, including mixture of species, cleanings, improvement cuttings, thinnings, reproduction cuttings, and the various forms of removal cuttings are prominent in all programs, just as in the United States, but the work in many cases is much older and naturally has gone farther. More recently the need for knowing more about the interrelation between soil and humus conditions and silvicultural methods and results has become evident and many countries are undertaking investigations along that line, including not only chemical and physiological studies of soil and humus, but also ecological and biological studies. This is a class of work on which as yet practically nothing has been attempted in the United States. The study of the browse and herbaceous vegetation in its relation to humus formation, natural reproduction, and the condition of timber stand is in some countries being given more attention than in the United States.

European research in forest mensuration has an entirely different status from ours. Its problems are relatively simple because the behavior of the few species is relatively normal and the range of sizes and ages is small. The material available for study is more homogeneous in density and age, and is better known. Economic conditions are sufficiently favorable to permit in most cases the practical application of whatever meaures seem technically desirable. The information essential to practical forest management is already available.

As a result, European research in forest mensuration is mainly on fundamental principles or on refinements of technique, whereas ours is still confined mainly to the preparation of volume and yield tables. Europe

has an adequate set of volume tables, the notable work of the past decade being that of the Swedes on form class and form point. Yield tables are less necessary than with us because of long-term records of the actual productivity of almost every forested area, but excellent tables are in existence which go into considerably more detail than do ours on minor yields such as from thinnings. An important characteristic of the newer work particularly in the Scandinavian countries and in Finland, is the use of statistical technique.

While research in forest entomology and forest pathology is perhaps more directly a function of the forest research organizations in some other countries than it has been in the United States, it is doubtful if any of them have accomplished more. Europeans still retain the idea that pathology is largely a study of the diseases of dead tissue rather than of the tree as a part of its environment. From the scientific standpoint American control practice is now far ahead of anything abroad. Although economic conditions in Europe make it possible to remove even single trees or small groups which have been attacked, foreign countries have nothing comparable with our blister rust control or the attempts to control the chestnut blight. Europe is carrying on a large amount of work on the identification and classification of fungi, and in this is ahead of the United States.

Sweden, Great Britain (with work primarily in the colonial field—Canada, India, and Australia), Germany, France, Switzerland, and Russia are the chief foreign countries interested in forest entomology. The United States is devoting a larger effort to forest entomological investigations and is accomplishing more than any other country. Most European countries go farther than the United States in control measures, such, however, as the purely empirical removal from the forests of attacked trees which is made possible by economic conditions. Europe apparently has nothing comparable with the scientific control of the browntail and gypsy moths in the United States through the use of parasites and insect enemies.

Apparently very few countries have studied the problems of grazing or fire damage and methods of protection against such damage.

Sweden and Finland possibly have the best organized forest experiment stations in Europe. These seem to be progressing along lines very similar to our own, but have the advantage of a more highly trained personnel. All things considered, however, including conception of the problem, organization, coordination of effort, technique, and current progress in all lines of work, the best American stations suffer little, if any, in comparison with the best European stations. More detailed statements on the forest research in European and other countries are included in the Appendix.

2. FOREST RANGE MANAGEMENT

Investigations in the United States on subordinate forest vegetation with particular reference to its use in livestock grazing and its effect upon timber growing have been confined almost entirely to the Federal Government and a few of the western State agricultural experiment stations. The work done to date has given us a fairly satisfactory working basis for the administration of grazing in the western National Forests, through the determination of a few of the most important principles underlying forest

range management and of the handling of livestock on the forest ranges. It has made a satisfactory beginning on a few of the fundamental problems underlying forage development in a very limited number of localities. In some localities where the damage to forest reproduction is greatest it has shown how serious that damage may be and has indicated, partially at least, what remedial or control measures are necessary. Only the barest beginning has been made on similar investigations in the East. Everything else is in the future.

While some European countries appear to have gone farther in investigating the relationship of the subordinate vegetation to the forest, no other country has attempted work comparable to ours on the utilization of the subordinate vegetation in livestock grazing.

3. FOREST INFLUENCES AND WILD LIFE

The number of instances in which the indirect influences of the forest have been intensively studied in the United States can almost be counted on the fingers of one hand. Europe possibly has a few more.

Our study of wild forest life up to the present time has been confined almost exclusively to taxonomy, habits, and life histories as a basis for game management or regulation. Wild life as a phase of forest management has hardly been touched. Such work as has been done is very largely that of the Federal Government and of a relatively few State organizations. Notable among recent developments is the establishment of the Roosevelt Wild Life Station by New York in connection with the State College of Forestry at Syracuse.

4. FOREST PRODUCTS

Nearly the entire contribution to American progress in forest products research is that of the Federal Government and of the forest industries. Here and there a State or endowed institution has turned out an excellent piece of work, but the aggregate is still small.

Aside from the popular appeal of this class of research which has made funds available on a somewhat more liberal basis, the one factor which is more responsible than anything else for American leadership over any other country is the establishment of the Forest Products Laboratory by the United States Department of Agriculture in cooperation with the University of Wisconsin. This has made possible a coordinated attack on many phases of the problem. Such subjects as kiln drying and air seasoning, improved pulping and distillation methods, the improvement of wood preservatives and of preservative treatments, and better boxes and containers have been sufficiently well covered in preliminary investigations to permit marked progress in commercial application. One important exception in the preliminary field is the direct attack on waste in the woods and the conversion plants, where much still remains to be done. From the standpoint of balance, too much of our forest products research up to the present time has been in the laboratory and too little in the forest, although this laboratory research is giving an invaluable background for intensive work in the woods. In addition to a large volume of preliminary work, considerable progress, more in fact than in any other country, has been made on fundamental investigations dealing with the laws of strength.

A fair beginning has also been made on moisture and heat relationships and the chemistry of wood and of cellulose. The work in general has already gone far enough and is sufficiently broad to give us a glimpse of a new science underlying wood utilization.

In some of the nations of the British commonwealth and Japan alone is forest products research organized on a basis comparable with ours. England has recently established a forest products laboratory with a very complete research program on which work is not yet fully under way. Miscellaneous work has also been done by several other institutions. The Canadian forest products laboratory, which was established in 1914, has operated on a small scale until recently. It has conducted the most comprehensive series of timber tests outside of the United States and published results on pulp and paper, wood distillation, wood chemistry, kiln drying, preservation, and pathology. Canadian universities have issued several publications on pulp and paper and wood chemistry subjects. The Forest Research Institute at Dehra Dun has a Branch of Forest Economy, which includes most of the subjects we class as forest products. A staff of about 30 technical men has laboratory facilities which have recently been enlarged to a scale exceeding those in any other country. Results have been published on timber testing, wood distillation, kiln drying, turpentining, tanning materials, pulp and paper, preservation, and wood technology, and a good deal of work has been done on the numerous tropical forest oils, resins, drugs, gums, dyes, and miscellaneous chemicals of India. A Federal forest products laboratory was started in Australia about ten years ago but soon became inactive. Several of the States have done miscellaneous work. In New Zealand timber testing has been started at Auckland University and a government forest products laboratory has been assured. Organized work on kiln drying, timber testing, and preservation is being carried on by the Forest Department of the Union of South Africa in cooperation with the railroads. In a number of instances Americans have been employed to assist in the organization of the laboratories referred to.

The central Japanese forest experiment station includes a branch of forest products with a comprehensive program. Reports have been issued on such forest products subjects as strength tests, calorific power and electrical resistance of wood, charcoal burning, essential oils, and white ants.

The outstanding work in France is apparently that on turpentine and rosin, long carried on at the University of Bordeaux. Recently the work has been enlarged by divisions of wood distillation, pulp and paper, and wood chemistry, but is limited to one species, the maritime pine. Apparently the only other products research in France is that of private corporations on kiln drying and preservation.

Germany has no centralized work on forest products. The state forest experiment stations have done little. One of the main government research bureaus makes tests of wood, glue, and paper, and another studies wood-destroying fungi. German scientific progress has come from the work of its universities and its industries. Germany has numerous chemists, pathologists, plant physiologists, and botanists who are working in the scientific field of wood formation and properties. It has also developed the industrial side in pulp and paper, distillation, and preservation.

Swiss and Austrian research in forest products is by universities and industries.

In Sweden the Royal Swedish Academy of Scientific and Industrial Research maintains a laboratory for experimental work on pulp and paper, including wood chemistry and waste sulphite liquor utilization. Swedish universities claim two of the best-known wood and pulp and paper chemists. The wood distillation industry maintains its own research laboratory. Norway is endeavoring to establish a governmental laboratory in close cooperation with the industries for pulp and paper work especially.

Finland has a government laboratory for the investigation of pulping methods with some general work on the properties of native species. One of the best-known wood chemists is at a university.

Forest products research in Holland seems to be in the hands of private consulting and testing organizations and the universities.

Forest products research in other countries seems to have been negligible.

The recently established forest products laboratories in England and its dominions and colonies have followed American precedents more or less closely in organization and in research technique for timber testing, artificial drying, wood preservation, and wood distillation, although fundamental work in general forest products subjects has not yet been undertaken. On the other hand, the much older work of the chemists, pathologists, and botanists in the universities of other foreign countries has frequently been of fundamental value. Most European countries have far better utilization than the United States. This, however, is more the result of long-continued economic pressure and of cheap labor than of forest products research.

5. FOREST ECONOMICS

American investigations of forest economics have been built largely upon statistics collected for other purposes. Most of the data other than that collected in the regular censuses have been very fragmentary and incomplete. In spite of the unsatisfactory nature of many of the basic data, the work done has brought out in concrete terms the most important phases of our present forest situation; the remaining stand of timber, the drain through lumbering, fire, and disease, our national requirements and those of different industries, the ratio of drain to replacement by new growth, the area of forest land, its distribution and potential productivity in relation to timber consumption. The findings have helped to crystallize popular opinion on the needs of the country as a whole and those of various regions, States, and industries. Our greatest present necessity is for a strengthening of basic data through a national forest survey and the reanalysis of our entire situation which this will make possible. Such a survey should give us a better knowledge of what timber we now have. It should give us a much fuller understanding of our present and probable future requirements and their relation to the actual and potential productivity of our forest lands. It should incidentally tell us how much land will probably be available for growing timber. In short, it should make clear how nearly we can hope to balance our national timber budget. Sec-

ond to a survey is the need for the collection and analysis of data showing whether or not forestry is financially profitable, and within limits how to make it profitable.

The greatest contributions to forest economics have been made by the Federal Government and the industries, although a large number of States have studied the requirements of their local industries.

Only a few countries other than the United States have undertaken economic research, at least through their research organizations. More has been done by individual investigators at the forest schools and elsewhere, and much statistical material is collected by the administrative branches in all countries with organized forest departments. A few of the more recent investigative programs include studies of present and future requirements, forest surveys, studies of forest organization, and studies of the sociological aspects of forestry.

6. FOREST RESEARCH AS A WHOLE

Many of the failures in the United States to make rapid or even reasonable progress in forest research may be ascribed to poor supervision or poor organization, or a combination of the two. In far too many organizations research has been and still is too largely on paper. Programs seem ambitious on paper but year after year passes without actual results. This is frequently true where a limited time only is available for research and the chief responsibilities of the organization are for other things. Research then becomes an incidental which is carried forward only as other work permits. Unfortunately the major activity rarely permits. Administrative activities and research do not combine advantageously. Research becomes incidental, investigators become handy-men, the doers of odd jobs, and investigations inevitably suffer. Research can be made most effective in executive organizations if it is separated entirely from administrative activities. It is possible in distinct research units to obtain a more sympathetic and effective administration and to offer sufficiently attractive careers to make it possible to obtain and hold men of the highest grade. Distinct research units will be most effective in the long run as constructive agents, in maintaining the highest forestry ideals, and in combating the supposedly financial considerations which constantly tend to lower standards of forestry practice.

There is probably the same need for a more clear-cut organization for research in the forest schools, otherwise it becomes incidental to teaching and progress is very slow. This is shown strikingly in Europe where the research at the forest schools is of long standing, and there is now a rather widespread tendency to organize research in the State forest services in order to get results urgently needed in the administration of the public forests. Larger faculties, a more definite organization for investigative work with regular programs and means of following up assignments and insuring results, should give research a far more satisfactory status in the forest schools.

It has required a vast educational effort over a period of 50 years to bring public opinion even to its present conception of our forest problem. This conception still falls far short of realities. A large section of the public, regardless of its vital interests, is still ignorant or indifferent.

Legislatures still make only the most inadequate provision for needs such as the planting of devastated lands, the purchase and effective administration of public forests, and the protection of forest lands against fungus and insect epidemics and fire, needs that to even the casual student seem glaringly obvious.

Still smaller as yet is the recognition of the signal part that research must play in the solution of the forest problem. Unfortunately this is almost as true among forestry organizations themselves as it is of the general public. As a result the big national problem of forest research has been attacked in a halting, desultory way without adequate resources, organization, suitably trained men, or the means of training men.

The committee's outline of a national program of forest research has resulted from the belief that it afforded the best available means to aid in bringing about the conception of what the United States needs. The committee is fully aware that any such statement of national research objectives can only be a small part of what will eventually be required. Full recognition of the need for a vastly increased program of research will not come without an educational effort similar to that which is being made for forestry as a whole. The owners of forest lands, the forest industries, the general public, and even foresters themselves must be brought to see the great opportunity which is offered by forest research, and to see the futility of depending upon other means. They must be dispossessed of the idea that research is an impractical activity, a mere luxury. They must be brought to see instead, as have some other industries, that it is the cheapest and most intensely practical means to practical ends. They must be brought to see that upon the proper enlargement and organization of research depends in large degree the substantial and lasting progress of the entire forestry movement in the United States.

The failure to appreciate fully the need for research and the unsatisfactory organization of some of that which has been attempted have been serious, but the most serious handicap in all forest research organizations in the United States has been wholly inadequate funds. As a result administrative efforts and frequently those on a large scale fail altogether or accomplish only in part what they should. Artificial forestation results in only partial stands. Fire protection is not fully effective, and draws year after year upon public treasuries and private resources for millions of dollars and repeats over and over again the same mistakes. Waste of timber continues at an appalling rate and cuts most heavily into the high-grade material for which our future need will be the greatest. Even the reasons for failures or partial successes in silvicultural measures are frequently unappreciated, as is also the possibility of great reductions in waste.

The most critical need in all forest research organizations is therefore for materially larger financial resources. What is now an incidental activity in many organizations must become one of their major efforts. Many organizations have not attempted anything, and those which are now doing most are falling far short of meeting their own or the public needs. If the necessary funds are forthcoming all the other difficulties can be met. If the necessary funds could be made available in regular sustained increases, known in advance, the work could be planned and developed on a much sounder and more satisfactory basis.

Plans for an adequate national budget for forest research have been suggested by the committee. The plans are general so far as most organizations are concerned, because they could not be otherwise in the time at the committee's disposal, but are more detailed for an organic act for the United States Department of Agriculture and for a Forest Research Institution. Annual expenditures for all classes of forest research in the United States by all agencies, which now probably total about $2,600,000, should by the end of the next decade reach from $9,000,000 to $12,000,000. It would not be unreasonable to expect the Federal Government to contribute from $3,000,000 to $4,000,000 of this total, the States through various institutions to add another $2,000,000 to $3,000,000, and the remainder to be taken care of through industrial research, private endowments of educational institutions, and private endowment of a Forest Research Institution. All organizations which wish to develop forest research may find the formulation of definite plans for a reasonable number of years a means to a much more rapid and ordered progress.

The demand for highly-trained investigators already far exceeds the supply. The enlargement in research organizations will carry with it a demand for greatly increased numbers of particularly able and highly-trained men. The demand may be expected to continue indefinitely. It places a new and heavy obligation on the forest schools which they will not easily be able to meet but which they will have to plan for with the greatest care. It places an obligation also on all research organizations to move as rapidly as possible towards the employment of highly-trained and thoroughly competent men. By so doing, such organizations can at one and the same time advance their research most rapidly and encourage men to spend the necessary time and money for advanced training. The enlargement of research organizations is going to offer an exceptional opportunity for careers to men of high ideals and outstanding ability who have the creative impulse.

The American forestry profession is under a definite obligation to see that some national program of materially strengthened research organizations is put through. The public has a right to look to the profession for advice and leadership. This leadership should come from consulting foresters, from those in the industries and the forest schools, as well as from those in the public service. Unless this leadership is forthcoming, foresters will fail in an essential part of the public service which the very nature of their profession obligates them to perform. They will fail in bringing about the research activities upon which we shall have to depend exclusively for a sound technical foundation for American forestry.

We have now reached the stage when the situation calls unmistakably for the development of forest research as a big national undertaking, on a scale commensurate with the movement to acquire national and other public forests; with the drive to place our entire forest area under protection against fire; with the effort to bring about the practice of forestry on privately owned lands; with the development of agricultural research in the United States. The national need for forest research requires in the future far greater breadth of view and greater vision than it has yet received.

APPENDIX

SUGGESTIONS FOR AN ORGANIC ACT

Some detailed suggestions follow on provisions for an organic act for forest research in the United States Department of Agriculture.

TITLE AND GENERAL PURPOSE

To insure adequate supplies of timber for the people of the United States, and to promote the full use for timber growing and other purposes of forest lands in the United States, through research in forest management, protection, utilization, range management, forest economics, and related subjects, and for other purposes.

FOREST EXPERIMENT STATIONS

Purpose. To determine, demonstrate, and promulgate the best methods for growing, managing, and protecting timber crops on forest lands, including methods of managing and protecting land containing a brush or chaparral growth for the purpose of maintaining favorable conditions of water flow and the prevention of erosion.

Kinds of Investigations, etc. Such silvicultural, protection against fire, dendrological, and other experiments and investigations, together with demonstrations and dissemination of results by other means, as may be necessary.

Stations. Authority to the Secretary of Agriculture to establish and maintain within the Forest Service the following stations for the forest regions indicated, and such additional stations in these and other important forest regions as he may deem necessary in carrying out the purposes of the act, including Alaska and the tropical possessions of the United States in the West Indies:

Northeastern Forest Experiment Station, for investigations of the spruce, white pine, hardwood, and other forests in New England and the Northeastern States;

Middle Atlantic Forest Experiment Station, for investigations of hardwood, hemlock, and other forests in Pennsylvania and in neighboring States;

Appalachian Forest Experiment Station, for investigations of the hardwood, pine, and other forests in the Southern Appalachian Mountains and adjacent forest regions;

Southern Forest Experiment Station, for investigations of the southern pine, hardwood, cypress, and other forests in the Southern States;

Lake States Forest Experiment Station, for investigations of the white pine, spruce, hardwood, and other forests in the Lake States;

Ohio-Mississippi Valley Forest Experiment Station, for investigations in the central farm woodlot region in Ohio, Indiana, Illinois, Kentucky, Missouri, Iowa, and in adjacent States;

California Forest Experiment Station, for investigations of the sugar pine, yellow pine, redwood, chaparral, and other forests in California and adjoining States;

Northern Rocky Mountain Forest Experiment Station, for investigations of western white pine, larch-fir, and other forests in Idaho, Montana, and eastern Washington and Oregon;

Pacific Northwest Forest Experiment Station, for investigations of the Douglas fir, Sitka spruce, and other forests in Washington, Oregon, and adjoining States, and in Alaska;

Rocky Mountain Forest Experiment Station, for investigations of the lodgepole pine, Engelmann spruce, western yellow pine, and other forests in Colorado, Wyoming, South Dakota, Nebraska, and in adjacent States;

Southwestern Forest Experiment Station, for investigations in the western yellow pine and other forests in Arizona and New Mexico, and in adjacent States.

Authorization. To be appropriated annually not more than $1,000,000. Provision that the amount for each station to be allotted out of any appropriation shall be determined annually by the Forester.

FOREST PRODUCTS

Purpose. To insure supplies of timber adequate for all national requirements and to encourage the profitable culture of forest lands, including farm woodlots, through the better utilization of forest products.

Kinds of Investigations. Experiments, investigations, and tests on the physical and chemical properties and the utilization of native and foreign woods and other forest products, including timber tests, wood preservation, tests of wood and other fibrous material for pulp and paper making, the relation of properties of wood to the growing conditions, commercial demonstrations of improved materials, methods, and processes, and for such other tests and investigations and means of making the results generally available as shall be desirable.

Location of Work. At the Forest Products Laboratory at Madison, Wis., or elsewhere within the Forest Service as may be necessary.

Authorization. To appropriate annually not more than $1,000,000 to carry out the above provisions.

Tropical Woods. To supplement the domestic supplies of hardwoods and other timbers in the United States until new supplies can be grown, or as long as they may be needed.

Authority to make within the Forest Service tests and investigations of South and Central American hardwoods and other timbers, to determine their suitability and availability for the industrial and other needs of the United States, including the collection or purchase of specimens and their shipment to the United States, travel and other expenses for investigating and reporting upon sources and supplies of these timbers in order to determine whether they are sufficiently accessible and are available in sufficient quantities to warrant tests, and for all other necessary expenses in connection therewith.

Authorization to appropriate annually not more than $50,000.

Forest Products Laboratory Building. Authority to construct at Madison, Wis., a suitable fireproof building or buildings with modern equipment for laboratory tests, including the moving and installation of existing equipment and the purchase and installation of additional testing and other necessary equipment, and such steam and other electrical connections as may be required for the use of the Forest Products Laboratory, and to accept, on behalf of the United States, from the regents of the University of Wisconsin a donation of such tract or tracts of land in accordance with Chapter 354 of the Laws of 1923 of the State of Wisconsin, as in the judgment of the Secretary of Agriculture may be suitable as a site for said building or buildings.

Authorization to appropriate not more than $900,000 to pay the cost

of building or buildings. Provision that construction work shall not be started until the Attorney General has indicated that the title to the donated land is satisfactory. Provision that not to exceed $50,000 may be used for the purchase of such new testing and experimental equipment as may be necessary for the efficient conduct of the work.

FOREST SURVEY

Purpose. To obtain and disseminate the information necessary as a basis for the national, State and industrial forestry policies.

Kinds of Investigations. Authority to the Secretary of Agriculture to have made by the Forest Service a complete survey of the forest resources of the United States to determine the location, quantity, and character of the various commercial timber species, present and prospective, including those now generally utilized or which may be utilized for the production of naval stores, and those suitable for the manufacture of newsprint and other important kinds of paper pulps; their availability for public and industrial uses; the amount and character of the present drain upon our forest resources, including cutting, losses by fire and diseases, and the character and amount of the present growth; character of timber and other forest products required annually for all domestic uses, together with the best indication possible of future requirements; and the area, location, and condition of lands chiefly valuable for timber growth and the estimated periodic increases in volume that may reasonably be expected to occur on such lands under suitable systems of forest management.

Authorization. To appropriate not more than $3,000,000, to be available until expended.

OTHER ECONOMIC INVESTIGATIONS

Kinds of Investigations. Authority to the Secretary of Agriculture to conduct within the Forest Service such other investigations concerning the economic aspects of forestry and related subjects as he may deem desirable, including investigations of the costs and returns from timber growing, forest taxation, forest insurance, and in general of the financial feasibility of growing timber, of the relation of transportation of forest products to timber growing, investigations of forest lands, including the relative value of the economic and social service which the land can render for timber growing, recreation, and other purposes, and of the production, distribution, and consumption of forest products.

Authorization. To appropriate annually not more than $250,000.

GRAZING RESEARCH

Purpose. To determine what utilization of forage by grazing may be consistent with the growing of timber crops and the protection of watersheds through the prevention of erosion, and to determine the best methods for the management of National Forest or other forest ranges, or of arid or semi-arid ranges, and to demonstrate and disseminate the results by the most effective means.

Kinds of Investigations. Authority to the Secretary of Agriculture to

conduct within the Forest Service, at Range or Forest Experiment Stations or elsewhere as may be deemed necessary, such investigations of the ecology of range plants, of their food values, of the carrying capacity of range types, of improved systems of range management, of methods of handling livestock, and the correlation of grazing and other uses of the forests, and such other experiments and investigations as he may deem necessary.

Authorization. To appropriate annually not more than $275,000.

PATHOLOGICAL INVESTIGATIONS

Kind and Location of Investigations. Authority to the Secretary of Agriculture to conduct within the Bureau of Plant Industry, at Forest Experiment Stations, the Forest Products Laboratory, or elsewhere as he may deem best, such investigations of diseases of forest and ornamental trees, and of those diseases which cause the deterioration and decay of wood and other forest products, including a study of the nature and habits of the parasitic fungi causing the chestnut tree bark disease, the white pine blister rust, and other epidemic tree diseases, as he may deem necessary, and of methods of prevention and control, and to demonstrate and disseminate the results by the most effective means.

Purpose. To discover methods of prevention of forest tree diseases and those which cause the deterioration and decay of wood and other forest products, through timber culture or otherwise, and new methods of control and of applying methods of reduction or control already discovered.

Authorization. To appropriate annually not more than $225,000.

ENTOMOLOGICAL INVESTIGATIONS

Kind and Location of Investigations. Authorization to the Secretary of Agriculture to investigate within the Bureau of Entomology, at the Forest Experiment Stations, the Forest Products Laboratory, or elsewhere as he may deem best, the history and habits of insects injurious and beneficial to forest trees or to wood or other forest products, the most effective methods of control or prevention of insect infestations, and such other experiments and investigations as he may deem necessary, and to demonstrate and disseminate the results by the most effective means.

Purpose. To determine and demonstrate the best methods of preventing infestations found to be injurious, through improved methods of timber culture, or of destroying or combating the infestations, or otherwise.

Authorization. To appropriate annually not more than $225,000.

ZOOLOGICAL INVESTIGATIONS

Kinds and Location of Investigations. Authority to the Secretary of Agriculture to conduct within the Biological Survey such experiments and investigations as may be necessary at Forest Experiment Stations or elsewhere as he may deem best to determine the life histories and habits of forest animals, birds, and wild life, both beneficial and injurious to forest trees, and their relationship to forest trees and to other forms of wild life.

Purpose. To utilize forest lands so far as may be consistent with

timber growing for the production of game and fur-bearing animals and other wild life, and to work out measures for the control of injurious rodents and other wild life, and to determine suitable systems of game and wild life management.

Authorization. To appropriate annually not to exceed $75,000.

FOREST FIRE METEOROLOGY

Kind and Location of Investigations. Authority to the Secretary of Agriculture within the Weather Bureau, at the Forest Experiment Stations or elsewhere as he may deem best, to study and investigate the meteorology of forest fire weather and forest fires, to make and disseminate forecasts of forest fire weather.

Purpose. To make fire control easier and more effective through adequate warning of forest fire conditions.

Authorization. To appropriate annually not to exceed $50,000.

COOPERATION

Authority to the Secretary of Agriculture to cooperate with other branches of the Federal Government, with State, county, and municipal authorities or agencies, educational institutions, organizations, corporations, and individuals, and to cooperate with foreign governments, institutions, corporations, or individuals in investigations of foreign woods for use in the United States; to receive money contributions from cooperators under such conditions as the Secretary of Agriculture may impose, the contributions to be covered into the Treasury as a special fund which is appropriated and made available until expended as the Secretary of Agriculture may direct, for offsetting the cost of authorized experiments, investigations, tests, and demonstrations, including the dissemination of information regarding results and for making refunds to contributors.

FOREST RESEARCH IN OTHER COUNTRIES

The status of forest research in a number of countries for which data are readily available is summarized briefly below. The list is not complete, nor is up-to-date information at hand for all the countries. It is evident that organized forest research is still in its infancy even in the older countries of Europe. Much remains to be done before all of the problems of even a single region can be regarded as being attacked systematically.

GERMANY

Following the report of a special committee in 1868, forest research stations were established as follows:

Baden (1870). Formerly directly under Domain Branch of Finance Department attached to Karlsruhe Technical College, and controlled by two commissioners; one from the forest service, one from the forest school. Now attached to the forestry department of the University of Freiburg, where it works in close cooperation with soils department.

At present, especial attention is being given to:

Silviculture of mixed stands.
Cultivation of exotics.
Methods of cutting.
Fertilizing in nurseries.
Soil studies, particularly problems of raw humus and forest litter.

Much study has been made of the planting of various species pure and in mixture; of thinning; of volume, growth, and yield. The program includes also studies of the effect of light and wind on tree growth and studies of various methods of improving the soil. About 350 sample plots are under observation.

Expenditures are about 9,200 marks ($2,190) a year, including salaries of assistants but not that of the Director of the Station, who is a professor at the University.

Saxony (1870). The Director and staff of the station consist of the Director and forestry professors of the Forest Academy at Tharandt. Recently important work has been done on the relation of soil and humus conditions to forest growth. Other investigations have dealt with planting methods, yields, volume measurement, influence of pruning on form of stem, effects of acid gases on vegetation, and phytochemical studies.

Prussia (1872). (This station covers also several smaller states.) The central station is connected with the Forest Academy at Eberswalde, under the same Director, and has the following divisions:

1. Forestry (silviculture), including seed-testing laboratory.
2. Forest meteorology.
3. Soil science.
4. Plant physiology.
5. Mycology (pathology).
6. Forest zoology.

There are also meteorological and forestry substations located in several forests, and the faculty of the Forestry College at Münden (Hanover) also carries on research.

The principal lines of research include natural and artificial reproduction, thinnings, cultivation of pure and mixed stands, and studies of the volumes, forms, and yields of the principal species.

The appropriation for the Eberswalde station for 1925 was 32,000 marks ($7,620), and for 1926, 36,500 marks ($8,690), not including the Director's salary.

Württemburg (1872). Originally connected with the Forest School at the University of Tübingen; reorganized and put under the State Forest Service, 1921, on an experimental forest near Tübingen, in order to get closer coordination of research and practical needs. The station works in cooperation with the soils and biology departments of the University.

Principal lines of work:

Soil maintenance and improvement; raw humus and growth stagnation.
Plant breeding and selection; studies of seed, etc.
Physiological and ecological studies: development of tree roots and crowns.
Growth and yield.
Forest management; silvicultural operations.
Forest protection.
Wood technology.
Cooperation in training forest officers and owners through educational courses.

Maintenance of a large number of permanent sample plots is emphasized. Many plots have been under observation for 50 years.

The personnel of the station consists of a Director, four permanent technical and two clerical assistants, and an indefinite number of temporary assistants. A soils expert was assigned to the station as Assistant Director, but the soils division was later transferred to Stuttgart.

Brunswick (1876). Under the Forest Service.

Hesse (1882). Attached to the Forestry Department of the University of Giessen, in charge of the forestry professors, but under administrative control of the Forestry Bureau of the Finance Department, which controls State forests. Work has been along the following lines:

Silvics: distribution of species, phenology, forest meteorology.
Reforestation: natural reproduction, source of seed for planting, introduction of exotics.
Soils: improvement of poor soils.
Forest management: thinnings and reproduction cuttings, methods of cutting, mixed stands, pruning.
Form, growth, and yield studies.

Alsace-Lorraine (1882). The main station was at Strassburg, in charge of the Forest School authorities and under control of the Finance Department. Information concerning status since the transfer to France not available.

Bavaria (1882). The station was originally connected with the forest department of the University of Munich, in charge of the faculties of forestry and allied sciences. There were seven divisions, each in charge of the corresponding professor:

1. Silviculture and utilization.
2. Forest management.

3. Forest policy and statistics.
4. Phytopathology and forest botany.
5. Agricultural chemistry and soil science.
6. Applied zoology.
7. Meteorology and climatology.

The station was reorganized in 1921 under control of the Forest Service, because administrative officers were impatient for practical results. The station is to conduct fundamental research and help administrative men in conducting "practical" studies. Work is carried on partly on a 1,500-acre experimental forest which is under the control of the professors of silviculture and forest management, and partly on the State forests.

Thuringia. (Covers several other small States.) The experiment station is connected with the Forest School at Eisenach.

The Union of German Forest Experiment Stations (formed in 1872) has concerned itself chiefly with formulating uniform principles and methods for forest measurements and major experiments, so as to make results comparable. It has also published results of committee work, such as pine yield tables, studies of exotics, and meteorological and phenological observations. It meets practically every year.

Research in forestry and related lines is also carried on by the National Biological Institute for Agriculture and Forestry, near Berlin.

Sources of information: Lorey's Handbuch der Forstwissenschaft (1st edition, 1888. Vol. 1, part 1; 3d edition (1912), Vol. 3; Forstwissenschaftliches Centralblatt, August 15, 1924; Allgemeine Forst-und Jagdzeitung, September, 1924; manuscript reports by U. S. Consuls at Berlin and Stuttgart.

AUSTRIA

Branch of Forest Research was established in the Department of Agriculture in 1874 to advise and supervise work at various provincial substations and plots on public and large private forests. Special emphasis was given to the study of:

Yield on various sites, with different methods of treatment.
Forest tools and machines.
Costs of various operations.
Afforestation and nursery practice.
Methods of cutting, including thinnings and reproduction cuttings.

In 1891 the Branch was changed to a Forest Research Institute, located at Mariabrunn, with personnel to carry on investigations directly. It consists of the following sections:

a. Silviculture
    Deals with seed control, afforestation, measurements, growth and yield studies, forest botany, phytopathology.
b. Forest chemistry and meteorology (1893).
    Includes soil and wood chemistry.
c. Wood technology and utilization (1895).
d. Forest zoology, especially entomology.

Activities of the Institute have been somewhat curtailed since the war. There is (or was in 1912) an advisory council with representatives of the Department of Agriculture, the Experiment Stations, the Agricultural College, and forest associations, to advise on the program and plan of work and on special projects for each year. The principal studies now

have to do with planting, silvicultural methods (including thinnings, improvement cuttings, etc.); protection from insects, animals, diseases, and smoke; and seed testing. About 275 sample plots are under observation.

In 1925 the permanent personnel of the Station consisted of four technical and four non-technical officers, and six temporary assistants were employed. The budget for 1925, including salaries and expenses, was 40,000 schillings (less than $6,000).

Some 390 scientific papers and books have been published by the Forest Research organization during its fifty years of existence.

Sources of information: Österreichische Vierteljahresschrift für Forstwesen 1924, pp. 19–22; Schwappach in Lorey's Handbuch der Forstwissenschaft, 3d edition. Tübingen, 1912, Vol. 3; mss. report, by U. S. Trade Commissioner at Vienna.

SWEDEN

The State Institute of Experimental Forestry was established in 1902 as a branch of the Forest Service. It was reorganized in 1912 with the same directing board as the Forest Academy. The laboratory and central office are at Stockholm. In 1921 a 3,600-acre research forest was acquired (in cooperation with a private company), and others have been added since then.

Up to 1921, field work was done on a large number of small sample plots all over the country. Since 1921 it has been mainly concentrated on larger permanent plots on special research forests or substations, each with a research officer in residence. In 1921 there were under observation 1,400 permanent plots, aggregating about 600 acres. Average annual expenditures for the Research Institute (1921–1923) were 248,400 kroner (normally about $66,600), of which about 10 per cent was for publication.

Principal lines of work carried on by the four sections of the Institute:

a. Forest Section:

Silvicultural methods.
Thinnings.
Origin of seed in relation to use in reforestation.
Methods of natural and artificial regeneration.
Growth and yield of principal trees.
Afforestation of heaths.
Races of trees and introduction of exotics.

b. Botanical section:

Chemical and physical studies of soil and humus types.
Raw humus and its effect on tree growth.
Ground vegetation in relation to soil types and forest growth.
Soil biology, including lower animals and bacteria, and their effect on the soil and humus.
Soil moisture problems, including formation of moors and bogs, and drainage.
Afforestation of moor-land.
Effect of freezing on soils and on plantations.
Artificial fertilizers.

c. Entomological section:

Biology of destructive forest insects, character and extent of

damage, and methods of control; relation of forest fires to insect infestation.

d. Supplementary section for regeneration problems in Norrland:

Seed production.
Seed germination.
Sowing and planting methods.

Sources of information: The Swedish Institute of Experimental Forestry (excerpt from Catalogue of Jubilee Exhibition in Gothenburg, 1923); Reports of the Institute.

FINLAND

The Forest Research Institute, founded in 1917, is under direct control of the State Forest Service and works independently of educational institutions. The forestry professors at the University of Helsingfors, together with the three professors in charge of the station, the Chief of the Forest Service, and one other member of the Forest Service, select the permanent personnel of the Station, and the Government may appoint other special investigators for definite periods. The appropriation for 1918 was 51,000 marks (normally about $10,000); for 1925 it was 625,100 marks (about $25,000 at current exchange). During the first few years the Institute was occupied chiefly with general studies in order to orient itself in regard to the most important problems, and consequently did little intensive technical research. The following subjects have been or are being studied:

a. Section of silviculture:

Distribution, characteristics, and importance of various types of forest.
Biological studies—inheritance and adaptation of racial forms.
Natural regeneration.
Planting methods.
Seed production.
Methods of management of spruce, including thinning and pruning.
Snow damage.
Ecological studies (relation of forest types and silvicultural treatment to subordinate vegetation; root competition of trees).
Cultivation of exotics.

b. Section of measurements:

Studies of form and growth.
Forest surveys.
Domestic consumption of wood.

c. Section of soil science:

Studies of swamps (origin, classification, drainage, afforestation).

Eleven experimental forests and three other tracts, totaling 131,000 acres, have been set aside for the exclusive use of the experiment station, and studies may also be made and plots established anywhere else in the State forests.

Sources of information: Reports of Finnish Forest Service; mss. report by U. S. Trade Commissioner at Helsingfors; O. Heikinheimo, Der Gründung der Forstwissenschaftlichen Versuchsanstalt Finnlands und ihre Tätigkeit. (Helsingfors, 1925.)

DENMARK

The section of Forest Research was established in 1883 as a branch of the State Forest Service. It was reorganized in 1901 with the Professor at the Forest Institute (Copenhagen) in charge, and is controlled as to program and budget by a commission representing State and private forestry and forest education, appointed by the Department of Agriculture.

The principal lines of work are:

- Growth and yield of forest trees.
- Cultivation of exotics.
- Forest soils, especially studies of humus, soil chemistry, and soil biology.
- Artificial fertilizers in forestry.
- Storms and frost damage to forests.
- Tree races and forms; studies of inheritance and adaptation.
- Tree diseases.
- Silvicultural management, including thinnings and natural regeneration.
- Manufacture and utilization of timber.
- Forest measurements.

Source of information: Det Forstlige Forsogsvaesen i Danmark. October, 1925.

NORWAY

There was a private experiment station at Solberg from 1908 to 1918. Another, supported by forestry societies, was established at Bergen (Vestland) in 1915; since 1922 it cooperates with the State station. The State Experiment Station at the State Agricultural College at Aas (near Oslo) was established in 1917, directly under the Forest Service (Department of Agriculture). The program and budget are controlled by a Commission representing the Forest Service, the forest school, private foresters, and private forest owners. Budget for fiscal years 1923–1924 averaged 47,000 krone ($12,600) for the main station. The present budget for the Bergen station is 26,000 krone ($7,000). To the end of 1923, about 90 permanent sample plots were established, mostly on State forests. Setting aside research forests is under consideration. Stations in Norway, Sweden, and Denmark cooperate on several projects.

The principal lines of work undertaken or proposed are:

- Management of even-aged and selective stands.
- Volume and yield studies.
- Natural reproduction.
- Seeding and planting; use of various species.
- Seed studies: origin of seed; seed production of native trees; germination tests.
- Phenological observations.
- Introduction of exotics, especially Douglas fir.
- Forest diseases.
- Studies of forest soils.

Sources of information: Meddedelser fra det Norske Skogforsoksvaesen, 1920–23; mss. report by U. S. Consul at Oslo.

FRANCE

The Station for Research and Experiments was established in 1882 at the forest school at Nancy. During the war its personnel was heavily drawn upon and the work practically ceased. The station was reorganized on July 1, 1920, and given a much wider scope. Although a governmental institution, it does not receive its support from the government budget, but certain forests near Nancy and elsewhere which have been turned over to it in usufruct support the station with its six substations in various parts of France and the forest school as well.

The major research projects are:

Natural regeneration of beech.
Reproduction of junipers.
Methods of working maritime pine for naval stores.
Management of poplars.
Control of erosion and floods.
Forest planting.

Sources of information: Schwappach, Vol. 3, 3d edition of Lorey's Handbuch der Forstwissenschaft, Tübingen, 1912; Proceedings of International Forestry Congress, Paris, 1913, p. 367.

Circular 878, Ministère d'Agriculture, Station de recherches et d'experiences instituée à l'École Nationale des Eaux et Forêts. Paris, July, 1920.

SWITZERLAND

The Central Experiment Station was established in 1885 (Schwappach says 1888) in connection with the forestry division of the Polytechnicum at Zürich. The Director is chosen from the forestry faculty; supervision is by a commission of seven members chosen by the Federal Council (must include three practicing foresters from the cantons). Has a large experimental forest and works all over the communal and cantonal forests. About 1,000 permanent sample plots are under investigation.

Work has been along the following lines:

a. Forest measurements: form, volume, etc.
b. Growth and yield studies.
c. Forest management: thinnings, methods of cutting.
d. Seed studies: biology, genetics, etc.
e. Nursery and planting practice.
f. Forest meteorology and forest influences, especially relation between forests and water.
g. Studies of forest soils.
h. Physiological studies: root development; compression wood; geotropism, heliotropism, and excentric growth; spectrophotometric studies.

Sources of information: Mitteilungen des Schweizerisches Forstliches Versuchsanstalts; also Schwappach in Vol. 3 of Lorey's Handbuch der Forstwissenschaft, 3d edition, Tübingen, 1912.

BELGIUM

A forest research office was established in 1896 as part of the Forest Service. It was reorganized in 1919 practically independent of, but still attached to the Forest Service. Headquarters are at Groenendael, where

there are nurseries, an arboretum, and a forest museum. It cooperates with the small forest experiment station of the State Agricultural College at Gembloux (established in 1920). There are also 24 arboreta in different parts of the country, for studying the cultivation of exotic trees on various soils, and two tracts aggregating 2,500 acres have been set aside for afforestation experiments.

Work is chiefly on problems of afforestation and reforestation, including:

Introduction of exotics.
Source of seed studies (provenience).
Nursery and planting practice.
Natural regeneration.
Pruning, thinning, and methods of cutting.
Soil improvement.

Studies are also made in wood preservation, and practical experiments in insect and fungus control. More fundamental studies of forest insects and fungi are made by experts from other branches. One of the duties of the Station is to give technical advice to private forest owners.

The present appropriation is only 55,000 francs a year, not including salaries (about $2,500 at current exchange).

Sources of information: International Review of the Science and Practice of Agriculture (Rome) Oct.–Dec., 1924; mss. report by U. S. Trade Commissioner at Brussels.

NETHERLANDS

The Forest Experiment Station was organized in 1919, under the Department of Agriculture. It is controlled by an advisory commission, consisting of two members of the Forest Service, one forestry professor from the Agricultural College, and two others with a knowledge of forestry. Originally at Amersfoort; transferred to Wageningen in 1923.

The Station has about 2½ acres for nursery and other experiments at Wageningen, and numerous sample plots in various parts of the country. It collaborates with the Botanical Laboratory at Utrecht, the Agricultural Experiment Station at Groningen, the Phytopathological Service and the Government Seed Control Station at Wageningen, and with private owners and commercial nurseries.

The staff consists of a Director, one permanent assistant, and several temporary assistants borrowed from the Forest School or the Forest Service. Average annual expenditures are about 23,500 guilders ($9,450), including salaries.

Progress in the following studies has been reported:

Origin of seed (Scotch pine).
Thinnings.
Influence of water level on vegetation.
Reforestation experiments with mixed pines.
Cultivation and growth of Douglas fir.
Influence of soil cover on the growth of pine in light sand.

Other studies on the program include physiological studies (development of root systems of pine), biological studies (seed production, heredity), natural reproduction (birch and pine), nursery practice, soil

studies (fertilizers, soil improvement), cultivation of exotics, and methods of management ("Dauerwald").

Sources of information: Mededeelingen van het Rijksboschbouwproefstation, 1922–1924; mss. report by U. S. Commercial Attache at The Hague.

NETHERLANDS EAST INDIES

The Forest Research Institute at Buitenzorg, Java, is a division of the Forest Service, in the Department of Agriculture, Industry, and Commerce. Under the Director there are five sections:

1. *Botanical and technological exploration:*
   Collects botanical and wood specimens about 3,000 species in the Archipelago, studies range and distribution, local nomenclature and uses, and identification of species. Had complete herbarium material and wood for 335 species at end of 1925.
   Personnel: 1 chief, 1 assistant chief, 2 technical assistants (European), 3 native assistants.
2. *Wood technology (or forest products):*
   Identification and structure of woods; mechanical, physical, and chemical properties; seasoning and preservation; inspection and grading; relation of growth conditions to technical properties; minor products. Industrial utilization is expressly excluded from Station's work.
   Personnel: 1 chief, 1 assistant chief, 3 native assistants, 1 European machinery expert.
3. *Silviculture (other than teak):*
   Silvicultural investigation of species important for timber or tannin; methods of cutting and regeneration; seed distribution; soils investigations; studies of tannins; protection from fire; grazing, etc.
   Personnel: 1 chief, 1 technical assistant (native), 2 native assistants.
4. *Silviculture and protection of teak forest:*
   Research on insects and fungi is carried on by the Institute of Plant Pathology, to which an entomologist is attached, and is not handled by the Forest Institute. About 600 sample plots for silvicultural studies.
   Personnel: 1 chief, 1 assistant chief, 1 technical assistant (native), 4 native assistants.
5. *Thinnings, yield, volume, etc.:*
   Studies basic for working plans. About 100 sample plots to date, mostly in teak.
   Personnel: 1 chief, 1 assistant chief, 3 technical assistants (1 European), several native assistants for field work and computing.

Source of information: Mss. report from U. S. Trade Commissioner at Batavia, 1926.

GREAT BRITAIN

Research has been under supervision of the Forestry Commission since 1920. Expenditure during 1924 was £7,139 ($34,000); average for five years 1920–1924 was about £6,900.

The principal lines of work are:

a. Forest management—growth, yields, thinning, etc. There were 149 permanent sample plots (mostly on private land) in England and Scotland on September 30, 1924.

b. Nursery and plantation studies, including methods of nursery practice, tests of various species, studies of root development, soil cultivation, sizes of planting stock, and season and method of planting.

c. Forest insect studies.

d. Botanical studies, including diseases of nursery stock, forest ecology, studies of formation of peat and its relation to forest growth, and hybridization experiments with larch. These studies are mostly carried on at the universities, with grants from the Commission's funds.

The above applies to forest research under the auspices of the Forestry Commission only. Other institutions, such as the Imperial Institute, carry on forest products investigations, and more or less unsystematized study of various silvicultural problems is done on many private estates. The Imperial Forestry Institute was established in 1924 at Oxford, as a center of postgraduate work and research. It is controlled by a Board of Governors, of whom four are nominated by the Universities and four by the Forestry Commissioners and the Colonial Office. It is supported by a grant of £2,000 from the Forestry Commission and more than £3,000 contributed by the Dominions.

The Commission is also making a detailed forest survey of England, Wales, and Scotland, and a census of production of saw timber, mine props, firewood, and other products.

The Department of Scientific and Industrial Research has created a Forest Products Research Board which includes two members of the Forestry Commission. This Board has appointed a Director of Research and is now in process of setting up a Forest Products Research Laboratory, whose primary duty will be to determine ways and means of securing more efficient utilization of timber. The cooperation of established institutions equipped to deal with certain portions of the work, such as the Forestry Commission, the Royal Botanic Gardens at Kew, the Imperial College of Science and Technology, the Imperial Institute, the Imperial Forestry Institute at Oxford, and the National Physiological Laboratory, has been obtained. The work of the Laboratory itself has been organized under eight sections—Timber Mechanics, Seasoning, Wood Technology, Pathology, Utilization, Wood Preservation, Woodworking, and Minor Forest Products and Chemistry.

Sources of information: Fourth and Fifth Annual Reports of the Forestry Commissioners, 1923–24; Report of the Scientific and Industrial Research, 1924–25; Forest Research in Great Britain, prepared for the World Forestry Congress of 1926.

CANADA

The first work was done by pulp companies. The Commission of Conservation commenced studies in Quebec in 1917, and the Dominion Forest Branch started an experiment station at Petawawa (Ontario) in 1918. It also cooperates with the Laurentide Company in their experiment

station at Lake Edward, P. Q. Five other tracts (two in Quebec and three in New Brunswick) have also been set aside as permanent forest experiment stations. The Petawawa tract embraces 63,360 acres, and the other six aggregate 6,000 acres. The Dominion Forest Branch spends $50,000 a year for silvicultural research in eastern Canada.

Studies undertaken by the Dominion Forest Branch, independently or in cooperation with provinces and private companies, include:

a. Work on pulp lands in eastern Canada:
  Natural and artificial regeneration on cut-over and burned-over land.
  Methods of management to insure continuous production.
  Thinning.
  Volume and growth studies.
b. Work on white pine lands in eastern Canada:
  Methods of management.
  Thinnings.
  Yield studies.
c. Similar work on Dominion reserves in western Canada.
d. Construction of general taper tables.

The Dominion Forest Branch established a Forest Products Laboratory (1914) at Montreal, in cooperation with McGill University, which carries on a variety of work under the general heads of (a) pulp and paper; (b) timber physics; (c) timber tests (mechanics); (d) wood preservation; besides several miscellaneous projects. The Dominion cooperates with the University of British Colombia in maintaining a similar laboratory in British Columbia. The Dominion appropriation for these laboratories was $132,400 in 1925.

The *British Columbia* Forest Service carries on some silvicultural investigation, as does the Forest Service of *Ontario* (in cooperation with the University of Toronto). The establishment of two forest experiment stations in 1924, with an annual appropriation of $10,000 each, is reported.

Quebec decided in 1923 to establish a Bureau of Research in the Provincial Forest Service, with an annual appropriation of about $25,000, to study:

a. Tree seed: origin, production, storage, germination.
b. Nursery practice.
c. Natural regeneration, including thinnings and improvement cuttings.
d. Growth, volume, and yield.
e. Diseases and injuries.
f. Cultivation of exotics.
g. Forest soils and land classification.
h. Protection against fires, insects, and fungi.

Sources of information: Forest investigative work of the Dominion Forest Service, by W. G. Wright, 1923; Forests of Quebec, by G. C. Piche, 1923; Statements prepared for the British Empire Forestry Conference by Forestry Services of British Columbia (1920), Quebec (1920), Ontario (1923).

INDIA

The Central Institute at Dehra Dun handles the more general problems in silviculture, etc., and correlates the work of the provincial research

officers. It also maintains forest products laboratories. The work falls under five branches:

1. Silviculture: Natural and artificial regeneration, cultivation of exotics, seed studies, nursery practice, thinnings, methods of management, silviculture of pure and mixed stands, light burning, form and volume, growth and yield, physiological studies (twisted fiber, effect of resin tapping on growth, etc.,) silvics of various species.
2. Forest botany: Forest herbarium and identification of trees, plants, fungi, etc., dendrological studies, forest pathology.
3. Forest economy (forest products): Sections of wood technology, timber seasoning, timber testing, minor forest products, wood utilization, wood preservation, paper and pulp, and tannins.
4. Forest entomology.
5. Forest chemistry: deals chiefly with gums, oils, resins, oleo-resins, and dyes.

Expenditures of Central Institute for fiscal years 1922, 1923, and 1924 averaged Rs 589,000 ($191,000). This includes the educational work of the Institute.

Most of the field work in silvicultural research is done by research officers attached to provincial forest departments in Assam, Bengal, Bihar and Orissa, Bombay, Burma, Andamans, Coorg, Central Provinces, Madras, Punjab, Northwest Frontier Province, and United Provinces. The provinces also carry on some forest products research, mostly in connection with lac and other minor products.

The Economics (Forest Products) Branch is by far the most important at the Central Institute, and is well equipped with buildings and apparatus. It absorbs nearly 60 per cent of the total expenditure, while the Silviculture Branch spends less than 10 per cent of the total ($14,700 in 1924). Figures on expenditures by the individual Provinces are not available.

Sources of information: Forest research in India, 1922–1923. Simla, 1924; same for 1923–1924, Calcutta, 1925.

UNION OF SOUTH AFRICA

Early research, covering principally problems of afforestation (planting, seeding, nursery practice, and introduction of exotics), was largely unorganized. The Research Branch of the Forest Department was established in 1912, and a laboratory plant was started at Pretoria in 1920. There is one small experiment station at Deepwalls, Cape Province.

Projects undertaken so far (1924) include:

a. Silviculture and forest botany:

Tests of exotics, seed collection, growth, natural and artificial regeneration, silvical characteristics and requirements of important trees; dendrological studies.

b. Timber investigations:

Seasoning, preservation, mechanical tests, minor products (fibers, tannins).

c. Insects and fungi:

A small amount of cooperative assistance from Division of Entomology and Botany.

Annual expenditures amount to about £3,000 ($14,600), including salaries. Some investigations in timber preservation and economical utilization are also made by mining companies.

Sources of information: Statement relating to the Union of South Africa, prepared for the British Empire Forestry Conference, Ottawa, 1923; report of Forest Department, South Africa, 1924; mss. report by U. S. Consul at Johannesburg.

NEW ZEALAND

Forest research was first undertaken in 1921. It is carried on by the Forest Service in cooperation with the botanical and engineering departments of the University Colleges (Aukland, Wellington, and Canterbury). Expenditure by the State for the fiscal year 1921 was £223; in 1925 it was £4,589 ($22,400). There are two experiment stations, one for general research and one for study of sand dune reclamation.

The principal lines of work are:

a. Silvical and ecological studies of forest types, including natural regeneration, seed germination, seedling growth, site requirements, etc.

b. Silviculture and management, including under-planting, natural regeneration, growth, volume, yield, methods of management, slash disposal, thinnings, fire damage, and intensive management of a 5,000-acre experimental forest.

c. Afforestation (especially exotic conifers), including nursery practice, sowing, planting, growth and treatment of plantations, and seed collection. A national arboretum of 50 acres is being established at Rotorua, to include some 400 species of conifers.

d. Sand dune reclamation on 2,000-acre experimental tract.

e. Grazing and game management.

f. Forest products investigations, embracing projects under the sections of timber mechanics, timber physics (especially seasoning), wood preservation, derived products (distillation and pulping), and industrial investigations (grading rules, utilization, mill studies). Emphasis is laid on utilization of secondary species and of sawmill and other waste.

g. Economic studies, including a forest inventory of the Dominion, a survey of wood-using industries, and economic aspects of waste utilization.

h. Plant pathology: studies of forest insects and fungi are carried on in cooperation with the Biological Section of the Department of Agriculture.

Sources of information: "Forests and Forestry in New Zealand," (Prepared for Imperial Forestry Conference, Ottawa, 1923); Annual Reports of the Director of Forestry for the years ended 31st March, 1923 and 1925.

AUSTRALIA

There is no Federal forest experiment station, but some research is done at the extensive nurseries and plantations at Canberra. The Commonwealth government spent £597 for research in 1925, and plans to spend £3,000 ($14,600) in 1926.

Of the States, no forest research is reported for Victoria and Tasmania, and none of the States has an experiment station.

New South Wales has permanent plots for the study of natural and

artificial reforestation and afforestation, thinning, growth, and cultivation of exotics.

Queensland carries on experiments in nursery and planting work, cultivation of exotics, natural regeneration, growth and yield.

South Australia has plots for study of yield in pine plantations, and has carried on seasoning experiments.

Western Australia studies natural reproduction, nursery practice, timber seasoning, and preservation. The government entomologist cooperates with the Forest Service, and a study of tannins and other forest chemical investigation has been carried on by the Institute of Science and Industry.

Sources of information: Mss. reports from U. S. Trade Commissioners at Sydney and Melbourne.

ALGERIA

The Forest Research Station of northern Africa was established in 1911 under the Algerian Forest Service. It is responsible also for research in Tunisia and Morocco. The station, laboratory, library, and forestry museum are located in a State forest near Algiers.

A program has been outlined as follows, but, owing to inadequate funds and personnel, comparatively little has been accomplished:

a. Forest meteorology: including effect of forests on rainfall, temperature, humidity, etc., and climatic requirements of various forest trees.

b. Forest soils: chemical, physical, and topographic studies.

c. Regeneration of forests, natural and artificial, including introduction of exotic species.

d. Cork production and diseases.

e. Forest management: growth, yield, methods of treatment, effects on wood of harvesting cork and resin.

f. Miscellaneous scientific studies: ecological investigations, forest successions, mycorrhiza on forest trees, plant and animal parasites of trees, dendrological studies, etc.

g. Organization of library and collection of woods, photographs, pathological and teratological material, animal and plant parasites, and forest herbarium.

Sources of Information: Bulletin de la Station de Recherches Forestières du Nord de l'Afrique; mss. report by U. S. Consul at Algiers.

JAPAN

The Central Experiment Station for Japan proper (Honshu, Shikoku, Kyushu, Ryukyu) with two sub-stations covers the following subjects:

1. *Reforestation problems:*
   - *a.* Soils, soil bacteria, artificial fertilizers.
   - *b.* Seed studies, seed production.
   - *c.* Nursery and planting practice.
   - *d.* Introduction of exotics.
   - *e.* Physiological studies.
   - *f.* Dune fixation.
   - *g.* Natural regeneration.
2. *Forest products:*
   - *a.* Timber mechanics.

b. Timber physics.
c. Seasoning.
d. Preservation.
e. Wood utilization.
f. Wood distillation and charcoal.
g. Rosin and turpentine.
h. Resins, dyes, oils, drugs, fibers, edible fungi.

3. *Forest management:*
   a. Forest measurements.
   b. Growth and yield studies.
   c. Silvicultural systems.
4. *Forest protection:*
   Insects, fungi, mammals, natural factors.
5. *Forest meteorology.*
6. *Problems connected with light burning, grazing, and other combined agricultural and forestry use.*
7. *Seed-testing laboratory.*

There are also forest experiment stations in Hokkaido and Formosa, and the Bureau of Crown Forests also maintains one. Plans have been made for a station in Korea.

Source of information: Forestry of Japan, Tokyo, 1923.

CZECHOSLOVAKIA

Forest research is under a special branch in the Ministry of Agriculture, and is controlled as to general policy and budget by an advisory council which includes the chiefs of the various divisions of agricultural research (forestry, agronomy, animal industry, etc.) and a professor of the College of Agriculture and Forestry. The program of work is formulated by a committee consisting of a representative of the Forest Service and the chiefs of the various sections of forest research. At present there are six of these sections:

1. Biochemical (at Prague): biochemistry and physiology of plants; biochemistry, biology, and physical properties of soils and their influence on timber production.
2. Silviculture and biology (at Brno): heredity, laws of growth, cultivation of exotics, studies of seed production and nursery practice, artificial and natural reproduction.
3. Protection (at Prague): pathology and entomology.
4. Economy (at Brno): forest management, regulation, dendrometry, valuation.
5. Technology and utilization (at Banska Stiavnica): forest tools and machines, grading of timber, mechanical and chemical properties, logging and manufacturing methods.
6. Forest policy (not yet organized): statistics, legislation, forest organization, taxation, tariff, etc.

The program for the immediate future includes:

Section 1: Nursery fertilization.
   Biochemical processes in conifer and broadleaf forests on different sites.

Effect of light upon decomposition of litter and chemical composition of humus.
Section 2: Various defoliating insects, bark-beetles, and weevils.
Reasons for disappearance of certain species in Bohemia.
Section 3: Remeasurement of sample plots.
Phenology.
Silvicultural systems and growth.
Arboretum and cultivation of exotics.
Silviculture on pasture lands.
Seed collection.
Section 4: Surveying methods.
Dendrometry.
Section 5: Seasoning.
Preservation.
Wood-destroying fungi.
Utilization of beech.

Nine experimental tracts have been set aside for use of the stations. The annual appropriation for forest research is 1,000,000 crowns (about $30,000 at current exchange).

Source of information: Mss. report by U. S. Commercial Attaché at Prague.

HUNGARY

Forest research is under the Forest Department of the Ministry of Agriculture. The principal experiment station is at Sopron, and the Director is a professor at the College of Mining and Forest Engineering. There are also two small stations for experimental planting on alkaline and sandy soils. The budget for 1926 is 130,873 gold crowns ($26,500), including research and forest development (soil improvement and planting). How much of this is for research is not known.

The program includes the following subjects:

Chemical and biological studies of soil and litter, including bacteria, insects, larger animals, decomposition of litter, treatment of the soil, etc.
Physiology and biology of trees, including structure, form, heredity, breeding of improved races, ecology.
Forest pathology and entomology.
Biological and ecological studies of fish and game animals.
Forest influences and meteorology.
Nursery studies—seed-testing, fertilizers.

Source of information: Mss. report by U. S. Consul at Budapest.

ITALY

The National Forestry Institute was established in 1914, primarily for research, secondarily for instruction. A Forest Experiment Station was added in 1922. The station is located at Florence, where it has a nursery and a small experimental tract. It also has land at Vallombrosa, where is located one of the most complete arboreta in the world. Experiments are carried on in all parts of Italy, in private and municipal as well as State forests. The personnel of the station consists of a Director and one per-

manent assistant. The appropriation is 90,000 lire ($3,600 at current exchange), and cooperating agencies contribute additional funds and assistance.

The investigative program includes the following:

1. *Economics, sociology, and legislation:*
   Forest resources and requirements.
   Sociological aspects of forestry.
   Forest policy, legislation, tariffs.
2. *Silviculture, alpiculture, wood technology, and utilization:*
   Seed extraction and germination.
   Sprouting of broad-leaved species.
   Methods of handling individual species.
   Studies of industries.
   Properties of woods.
3. *Dendrometry:*
   Valuation.
   Working plans.
   Growth, form, and yield studies.
4. *Hydrography:*
   Erosion and flood control.
5. *Forest botany:*
   Forage and cover plants.
   Phytogeography.
   Medicinal plants—utilization of subordinate forest vegetation.
6. *Pathology and physiology:*
   Chestnut ink disease.
   Pine diseases.
   Treatment of wood by electric osmosis.
7. *Forest chemistry:*
   Resin and turpentine.
8. *Forest geology and mineralogy:*
   Soil studies.
   Relation between soil and geological formations and flood control, erosion, etc.

Sources of information: L'attivita del R. Istituto Superiore Forestale Nazionale dalla sua fondazione al 1924 (Florence, 1924); A. Pavari, Relazione sulla attivita della Stazione Sperimentale di Selvicoltura dal 14 aprile al 30 giugno 1923; *same* for 1923–1924.

POLAND

Up to the end of 1925 there was no forest experiment station, although a small amount of investigative work was done by the professors of forestry and related subjects in the Universities of Warsaw, Posen, and Cracow. At the request of the government, these professors recently drew up a program for forest research, which included the following subjects:

1. *General:* phytogeographic, ecological, biological, and soil investigations; forest type and site classification.

2. *Silviculture:* natural and artificial regeneration with various methods of management, seed provenience, thinnings and cleanings, cultivation of exotics, nursery and planting studies, mixture of species, use of fertilizers, afforestation of bare land.

3. *Management:* volume, form, yield, grades, management of small forests.

4. *Protection:* insects.

5. *Technology and utilization:* durability of wood, preservative treatment, technical properties, defects, properties of timber killed by insects or fire, resin extraction, scientific management in the timber and transportation industries.

Source of information: Mss. report by U. S. Commercial Attache at Warsaw.

LATVIA

A forest experiment station was established in 1925, under the control of a commission consisting of the Director of the Forest Service, the chief of the division of forest management, and two other foresters. The central office is at Riga, and there are now seven experimental tracts in various parts of the country.

Proposed studies include:

Soils and forest site classification.
Afforestation.
Grazing and reproduction.
Sprouting of broad-leaved species.
Natural and artificial pruning and its influence on technical properties of the wood.
Heart rot of spruce and aspen.
Intermediate cuttings.
Volume and yield tables.

Because of the similarity between Latvian and German conditions, there is some hesitation about embarking on a program that will duplicate what the Germans have already done or are doing, and it is planned to work only on Scotch pine for the present.

The budget for 1926 amounts to 3,000 lats (about $575), not including salaries.

Source of information: Mss. report by Latvian Forest Department, submitted by U. S. Commercial Attaché at Riga.

RUSSIA

The beginning of experimental work in forestry dates back to 1843 when a model forest was organized to demonstrate the possibility of reforesting prairies and determine the most suitable species. In 1913 there were 15 forest experiment stations. Their activities were controlled by a special permanent Commission which was organized in 1906 as a part of the Department of Forestry. From 1906 to 1915 the appropriation for forest experiment stations rose from some $18,500 to $43,000 a year. Until 1917 the results of the work appeared in the Transactions of Forest Experiment Stations, of which 60 volumes were published, covering a wide range of topics. In 1916 the forest experiment stations began gradually to die out, and in 1918 their existence ceased entirely. In 1923 there was a revival of interest, and at present ambitious plans have been formulated for developing the work.

The forest experiment stations under the old regime accomplished a

great deal of good, especially in developing methods of reforestation based on the practical experience in the prairie and also the forest regions. The stimulus given by this work may be judged from the fact that while before 1899 not over 20,000 acres were reforested annually, by 1912 close to 200,000 acres were planted each year. Another achievement was the development of forest meteorology and forest ecology.

The stations were criticised because they did not work according to a general plan for the country as a whole and because the problems undertaken were sporadic, often of an academic character and not directed to vital management problems. These faults are now to be corrected and the following plan has been approved:

Organization.—This is to consist of:

1. Bureau of Forest Experiment Stations, attached to the central Department of Forestry in Moscow.

2. Central Forest Experiment Station in Moscow, with a branch in the northwestern region. This is to unify, direct, and control the work of all the regional stations. This station is also to develop the methods and technique of scientific investigations, organize experiments and observations on a nation-wide scale, and work out the scientific basis for the general theory of forestry.

3. Regional Forest Experiment Stations—local organizations—which are to work on important regional problems of forest management according to plans approved by the Central Station.

4. Model Forests. Some of the best organized forests of the country are to be used for verifying on a large practical scale the results worked out by the nearest Regional Experiment Station. These are also to be used for conducting observations and simple experiments of national scope under the direction of the Central Experiment Station, but controlled by the Regional Experiment Stations.

5. Demonstration Forests attached to Forest Schools. Since the Forest Schools are also state institutions, the School Forests are in a sense local stations, whose activities are unified with the plans of the Bureau of Forest Experiment Stations and the Central Experiment Station in Moscow. There are some 24 such Forest Schools of the higher and lower grades.

The organization, then, consists of one Central Bureau of Forest Experiment Stations, of an administrative character, in Moscow, controlling the entire work of the experiment stations. The more theoretical and scientific phases of the work are being developed by a Central Experiment Station in Moscow, which has a branch in the northwestern region, while the more practical problems, which have to do chiefly with forest management and natural reproduction, are to be worked out by Regional Experiment Stations, in addition to a number of National Forests and School Forests to be used for demonstration purposes and for verifying the results of the Regional Experiment Stations in a practical way. The country is divided into six forest regions, for each of which there is to be one Regional Experiment Station. For carrying out this plan an appropriation of some $136,000 has been budgeted.

Source of information: Forestry in Russia and Its Future Outlook. Official publication of the Department of Agriculture prepared by a special planning commission, Moscow, 1924.

YUGOSLAVIA

A Forest Research Institute was established at the University of Zagreb in 1921. It is controlled by a Council composed of the forestry professors and professors in related subjects at the University. The Council elects the President of the Institute annually from its membership, and at the same time decides upon the program of work and the budget for the year. Each member of the Council conducts the investigations in his own line, and younger assistants will be attached to the Institute as they become available.

Field work was first undertaken in 1925, and was largely limited to an investigation of the Slavonian oak forests, which have been dying off to a serious extent for several years. It is planned later to study the methods of reforestation of the Karst region, and the national timber requirements and production. Expenditures for 1925 were about 33,000 dinars ($500 at current exchange).

Source of information: Mss. report by U. S. Consul at Zagreb.

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